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Development of the PAINTER Engineered Management System

by
Orange S. Marshall, Jr.

PAINTER is an Engineered Management System (EMS) designed to: (1) help schedule and maintain exterior painting of military facilities, and (2) keep records on lead-containing paint on the interior of those facilities. The system includes an inventory procedure, a condition rating procedure, and tools to help installation managers determine, optimize, and prioritize painting maintenance and repair (M&R) requirements. PAINTER also generates reports that help facility engineers create both short- and long-term M&R work plans.

The overall condition rating procedure is based on the Coating Condition Index (CCI), which is composed of two separate condition ratings: the Appearance Condition Index and the Film Condition Index. These indices form the basis for the other PAINTER EMS engineering tools, including condition prediction tools, economic analysis tools, prioritization and optimization models, project level and building complex level management tools, and paint history. This report describes the refinement of the CCI, and development and description of the other tools. Paint condition assessment procedures and recommended M&R actions for lead-containing paint in child-related facilities are included. This report also identifies the need for PAINTER training and provides a draft training outline.

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PAINTER is an Engineered Management System (EMS) designed to: (1) help schedule and maintain exterior painting of military facilities, and (2) keep records on lead-containing paint on the interior of those facilities. The system includes an inventory procedure, a condition rating procedure, and tools to help installation managers determine, optimize, and prioritize painting maintenance and repair (M&R) requirements. PAINTER also generates reports that help facility engineers create both short- and long-term M&R work plans.

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1 Introduction

Background

The U.S. Army owns over 120,000 buildings, for which annual paint maintenance, repair, and replacement costs are estimated at over $26 million. Paints and coatings are important installation components because they enhance the appearance of buildings and protect construction materials from attack by environmental and biological agents such as moisture and mildew. The appearance and condition of facilities impact the durability of some substrates and also affect troop morale. Effective management of the Army's facilities is vital to ensuring the maximum return on this large investment.

Moreover, as the Army's infrastructure ages and deteriorates, the cost of maintenance and repair (M&R) increases. In an atmosphere of shrinking resources and a growing M&R backlog, the Army needs a tool to optimize the maintenance of its buildings' paints and coatings to maintain this property investment and the troops' quality of life to include the safety of their dependent children from lead paint hazards.

The U.S. Army Construction Engineering Research Laboratories (USACERL) has been developing a series of Engineered Management Systems (EMSs) to help Army managers make M&R decisions for military facilities based on technical information. USACERL-developed EMSs make systematic use of engineering technology to determine when, where, and how to best maintain facilities. EMSs are based on engineering tools that use information from inventories and condition surveys to produce data for management at both the network and project levels. Each EMS consists of: (1) an inventory procedure, (2) a set of standard distresses and a condition indexing procedure based on those distresses, (3) condition prediction models, (4) M&R guidelines, (5) an economic cost analysis procedure, (6) an M&R history, (7) prioritization/optimization models, and (8) a report-generating function. The system provides technology-based condition and cost analyses to help managers reduce M&R costs by scheduling maintenance at the optimum time, before costly emergencies and catastrophic failures occur.

PAINTER is an EMS that can provide managers with information on an installation's paints and coatings. The Coating Condition Index (CCI), one of PAINTER's basic engineering tools, provides an objective, consistent condition assessment of paints and coatings to help determine service life. This tool will help installation Directorates of Public Works (DPWs) develop optimum maintenance and repair plans, and effectively budget and allocate M&R funds for their many buildings. This structured management system uses uniform, objective, condition evaluation procedures to schedule and monitor the effectiveness of applied M&R of paint.

Objective

The overall objective of this work was to develop and implement PAINTER, an EMS for maintaining the painting of structures on military installations. Specific objectives for this part of the project were: (1) to develop a Coating Condition Index (CCI), (2) to develop a consistent inspection procedure, (3) to develop paint M&R related engineering tools, (4) to define the reports PAINTER should generate, and (5) to identify needed training and develop a draft training outline to begin implementation of PAINTER.

Approach

This research was conducted in the following stages:

1. Recent literature on paint deterioration was reviewed.
2. Paint experts from both government and private industry were consulted to develop the condition survey procedure, the Coating Condition Index for paint, and related engineering tools.
3. Economic analysis procedures were developed.
4. Prioritization/optimization models were developed.
5. Models for paint condition prediction were developed.
6. Project and network (building complex) level management tools and reporting data were developed.
7. M&R alternatives for PAINTER were developed based on current and projected paint conditions.
8. Training requirements and a training outline were drafted.

Scope

This research emphasized the development of the PAINTER EMS methodology. It addresses the maintenance management of exterior paints and coatings as well as management of lead-containing paint on the interior of child-related facilities. This report does not address technical information on software, software development, or software field testing.

Mode of Technology Transfer

It is recommended that the use of the PAINTER EMS should be incorporated into Engineer Manual (EM) 1110-2-3400, *Painting: New Construction and Maintenance* (Department of the Army [DA], 20 June 1980). Further technology transfer will be

conducted through the Facilities Engineering Applications Program (FEAP) field demonstrations and formal training. It is also anticipated that a Public Works Technical Bulletin (PWTB) will detail maintenance planning with PAINTER, and that PAINTER will later become a module of the BUILDER EMS currently being developed at USACERL.

2 PAINTER EMS Inventory Procedure

An inventory procedure was developed for PAINTER EMS based on measurement methods described by the Painting and Decorating Contractors of America (PDCA) for standard painting job estimation in their *1992 Estimating Guide* (PDCA 1992).

Before any inventory is collected, however, the basic inventory parameters must be defined. The basic maintenance unit for PAINTER EMS is a building or structure. The feasibility of using another basic maintenance unit such as substrate or paint type was investigated. However, since most paint M&R performed by the military is already based on buildings or structures, to minimize user confusion and database structure difficulties, the building was determined to be the best choice for a basic maintenance unit.

Each basic maintenance unit is further broken down into sections or faces. A section is the basic inspection unit for PAINTER EMS. A section is defined by the user and can be an entire building, one or more walls of a building, or a portion of a wall. For very long, tall, or curved walls, a face extends from specific identifiable features on its surface. For example, an expansion joint, a door, a vertical conduit, or similar features could divide faces on a very long wall. The support legs on a water storage tank could divide faces, as could a ledge or change of substrate in a tall wall. The appearance component of the condition survey evaluates the section level of a building so this level of the inventory is important to maintain proper impact of appearance paint problems or distresses.

Sections/faces are further broken down by component. Components are the individual items that make up the face. The PAINTER EMS inventory records the components that make up faces that compose buildings. Component examples may include doors, windows, soffits, walls, etc. The components may be further broken down into sub-components when necessary. For example a wall may consist of CMU and wood. The CMU part would be one sub-component and the wood portion another.

Some simple rules of thumb exist for measuring components for inclusion in the PAINTER EMS inventory (PDCA 1992, pp 3-8).

Rule 1. No object is considered less than 1 linear foot long and shall be measured as 1 sq ft per linear foot.* This rule is usually applied to such items as support brackets, electrical boxes, gutters, down spouts, handrails, conduit, and water faucets.

Rule 2. Pipes, rods, structural steel and lumber whose circumference or perimeter is less than 1 ft are measured as 1 ft, otherwise, when greater than 1 ft, the actual

* 1 in. = 25.4mm; 1 ft = 0.305 m; 1 sq ft = 0.093 m^2.

diameter is used. This rule would apply when figuring exposed piping of various sizes or open wood structures such as arbors, trellises, and the like.

Rule 3. No component part or member of an architectural object is considered less than 1 linear ft long and shall be measured as 1 square foot per linear foot. This rule is usually applied to such items as window frames, shutter louvers (slats), moldings, and vent louvers.

Rule 4. When an item is touching and/or adjacent to other items that do not have the same surface substrate, treatment (i.e., preparation or finish), application method (i.e., spray, brush, or roller), and accessibility in common, it should be listed as a separate component and measured at no less than 1 sq ft per linear foot. Typical examples are baseboards, chair rails, and frieze boards. A color change within the same surface would fall under this same ruling.

Rule 5. When items having equivalent surface substrate, treatment, application method, and accessibility change directions at sharp angles and continue for a significant distance in the new direction, then measurement of the object increases by the length of the new direction, but usually not less than 0.5 sq ft per linear foot. For example, a window sill may have a 4-in. top, a 1 to 1.5–in. edge and a 0.5–in. lip. Each surface should *not* be considered as a separate item; instead they are all considered as a whole, measuring 1 sq ft per linear ft. Examples of where this rule would apply would be when measuring a door, door frame, or a window sill.

Rule 6. When measuring nonuniformly shaped and/or curved items having equivalent surface substrate, treatment, application and accessibility, the added length of the surface due to its curving, change of direction, or nonuniformity must be measured. This is used for such architectural items as corrugated sheet metal, acoustical metal pan ceilings, fluted masonry, or board and batten siding.

Rule 7. Closely fabricated items having equivalent surface substrate, treatment, application, and accessibility should be measured as being solid. Typical examples are wire partitions, chain-link fencing, wire guards, and folding gates. In each of these cases, the posts, rails, and other framing members should be measured the same as pipes, rods, etc. mentioned in rule 2.

Rule 8. When a continuous surface is interrupted by a small opening, the opening is disregarded and considered part of the continuous surface. Any opening extending from floor to ceiling and exceeding 5 ft in width should be deducted. All openings 100 sq ft or larger are deducted. Thus, small windows, average doors, metal grilles, baseboards, molding strips, etc. are not deducted from the gross wall areas.

Rule 9. In the case of walls with windows in them, the number of windows and the square footage of the window openings will be recorded.

3 Coating Condition Index

The CCI was developed over a 2-year period by a team of paint experts from both the Federal Government and private industry. In addition, a representative from an Army installation Directorate of Engineering and Housing (DEH) was included in the development team so the CCI would better reflect DEH needs and capabilities. The CCI development team's first objective was to determine the feasibility of developing a CCI. After review and discussion of the concept the development of condition indexes for other USACERL EMSs, it was agreed that a useful coating condition index could be developed for paints and coatings.

The CCI is a numerical representation of the condition of a paint or coating on a building component. It is an indicator of the degree of degradation of the coating and the amount of M&R required to maximize the performance and life of the coating. When correlated properly, the CCI may be used as a tool for predicting future conditions, costs, and different maintenance strategy impacts. This chapter describes some of the basic theory used in developing the CCI.

Paint and Coating Systems

A paint system is a coating system that consists of a primer and a topcoat with any number of intermediate coats in between them. For building components, the number of intermediate coats may vary from none to many, depending on the substrate material, the environment, the desired paint life, and the number of times the component has been repainted in the past without removing the old paint.

A paint system serves two major purposes: to give a material some desired aesthetic quality, and to protect a material from the environment. Any condition that detracts from the aesthetics or from the paint system's ability to protect the substrate is called a *distress*. Consequently, a paint-condition evaluation must assess the significance of any distresses.

Coating Condition Index

The CCI is a number that represents a maximum value for perfect condition, minus the impact of any distresses present. A distress is an indication of deviation from perfect condition. USACERL-developed EMSs use 100 for a maximum value and assign different descriptive categories for specific value ranges in the rating scale down to zero. Table 1 lists rating scale ranges and their respective descriptive categories.

The CCI is based on survey results for structures and is the assessment of the extent of any visual distresses in the coating system. The CCI is actually a function of two

Table 1. EMS rating scale descriptive categories.

Rating Scale	Descriptive Category
86-100	Excellent
71 - 85	Very Good
56 - 70	Good
41 - 55	Fair
26 - 40	Poor
11 - 25	Very Poor
0 - 10	Failed

condition indexes: the Paint Appearance Index (PAI), based on *appearance distresses*, and the Paint Film Index (PFI), based on paint *deterioration distresses*. Therefore:

$$CCI = f(PAI, PFI) \qquad \text{[Eq 1]}$$

where:

f = some function.

The PAI is a function of the degree, extent, and percentage of contrast in the paint system's appearance such that

$$PAI = C - f(S, E, A) \qquad \text{[Eq 2]}$$

where:

C = a maximum condition index (100 for EMSs)
S = distress severity level
E = extent of distress
A = distress area percentage.

The PFI is a function of the type of substrate painted, the severity and extent of paint distresses, exposed substrate distresses, and deteriorated substrate distresses such that

$$PFI = C - f(T, F, X, D) \qquad \text{[Eq 3]}$$

where:

C = a maximum condition index (100 for EMSs)
T = type of substrate
F = paint film deterioration area
X = area of exposed substrate
D = percentage of exposed substrate deteriorating.

Distresses

A coating condition is based on the presence, severity, and extent of distresses. Severity levels may be high (indicating immediate attention is recommended), medium (which may be scheduled in the next annual work plan), low (which can be scheduled whenever the availability of time and manpower permits), yes (indicating that a condition is present) or no (indicating a condition is not present). Once the distresses and their associated severity levels are defined, corresponding M&R levels may be defined in terms of routine maintenance, minor repairs, moderate repairs, etc.

Different distresses impact the overall component condition differently. Some have little or no impact, and are classified as distresses only because of the special effort required to remedy them (e.g., mildew). Other distresses have high impact because they are the results of localized paint failure, making the substrate susceptible to damage by the environment. Examples of high-impact distresses for paint include peeling and blistering that penetrate to the substrate. Peeling and blistering that penetrate only to an undercoat are examples of moderate-impact distresses.

Distress Definitions

The first step in developing the CCI was to define distresses and other pertinent terms for the system. Distresses are classified into five basic types from least severe to most severe:

1. Building-specific distresses
2. Appearance distresses
3. Paint film distresses
4. Exposed substrate distresses
5. Substrate deterioration distresses.

Building-Specific Distresses

Building-specific distresses such as disconnected downspouts, leaking gutters, missing flashing and caulking, missing fasteners, or penetrations were identified as building-specific distresses. While distresses such as leaks may have an impact on paint performance, they have no influence on the CCI for PAINTER. However, such distresses *are* important when a paint contract is prepared, and they should be included in the remarks section of the condition survey. Doing so will highlight repairs that should be made before preparing (or in conjunction with) a paint maintenance contract.

Appearance Distresses

An appearance distress is a condition that detracts from the aesthetics of a structure. Aesthetic value is normally an arbitrary judgement made by whoever passes by. As a result, only appearance distresses visible when viewed from a distance of between

30 and 50 ft—the typical distance of an installation building from a street—are considered distresses.

Appearance distresses were identified as the development team began to correlate the maintenance requirements arising just from appearance (Table 2). Deduct values were assigned to the identified appearance distresses and evaluated through building inspections. The list was revised further as the team looked at more buildings and evaluated their impact and importance on the final CCI. The final appearance distresses and their associated definitions are listed in Table 3. The distresses include only those evident when a painted surface is viewed as a whole from a distance of 30 to 50 ft.

Paint Film Distresses

Paint film distresses are those that affect the integrity of the coating film. They can be detected visually, requiring no specialized equipment for evaluation. Paint film distresses are identified as *peeling*, *lifting*, and *missing* coat(s). Also, included is paint worn away by weathering, abrasion, or erosion so an underlying coat or the substrate is exposed. Table 4 describes the various paint film distresses.

Chalking, another common type of paint deterioration, is typically caused by the loss or breakdown of polymeric binders in some paint systems when exposed to ultraviolet light. Some paint systems are designed to chalk. The chalk protects the coating beneath the chalk from UV light which, in turn, provides substrate protection. Chalk, therefore, is not considered a paint film distress. When chalking wears away to the point where an undercoat or substrate becomes visible, it is considered weathering/erosion, a paint film distress. To the extent that chalking causes a visual contrast when it is rubbed off in places, it is classified as an appearance distress.

Exposed Substrate Distresses

This classification contains only one type. Exposed substrate is a condition where the substrate has no paint film. A substrate is defined as the base construction material of a building component. Included also as substrates are galvanized metal and stucco,

Table 2. Maintenance level work effort for distresses based on appearance only. (No film deterioration distresses.)

Condition Index Range	Maintenance Action
86 - 100	Nothing to do
71 - 85	No cleaning necessary
56 - 70	Localized spot cleaning or scrubbing
41 - 55	Localized or wide-spread cleaning or scrubbing
40 - 0	Extensive scrubbing and cleaning (Film Condition normally drives maintenance)

Table 3. Appearance distress level definitions.

Distress Level	Definition
Uniform	Consistent or not varying; having the quality of sameness.
Low Contrast	A small degree of variability in color or gloss from the surface norm.
High Contrast	A large degree of variability in color or gloss from the surface norm.
Localized	Few isolated spots or areas (typically 3 or less) of contrast across the surface of a face or management unit.
Wide-Spread	Many isolated spots or areas (typically 4 or more) of contrast across the surface of a face or management unit.

NOTE: Soiling, to include mildew, dirt, rust stains, tire marks, grass stains, graffiti, etc. and chalking, the powdery surface of a paint film caused by the disintegration of the paint binding medium during weathering that exhibits a non-uniform appearance are not true appearance distresses but typical examples of distress causes. They are, therefore, not included as definitions. However, since something needs to be done to deal with them when maintenance is performed, their presence should be noted in the condition survey sheet remarks section.

including the exterior surface material of manufactured wall systems such as "Drivit." Factory finishes, however, such as the finish surface of aluminum siding, are classified as coatings rather than substrates.

Substrate Deterioration Distresses

Substrate deterioration distresses are defined by example, e.g., *rust* for steel and iron products, *rotting and delamination* for wood and wood products, etc. For the most part, masonry should not be painted. Where it is painted, however, deterioration of masonry does not affect paint film on painted surfaces. Table 5 lists the deteriorated substrates identified during field evaluations for use by PAINTER EMS.

Table 4. Paint film distress definitions.

Distress Type	Distress Description
Peeling	Paint film with a detached edge or edges that protrude above the substrate often with a curved or bent appearance.
Lifting	Paint film that visually does not adhere to either the substrate or an undercoat, and that protrudes from the plane of the surface
Blistering	Bubbles within or between coating layers or between the substrate and the coating system which causes the coating to protrude from the plane of the surface.
Abrasion	The loss of material due to mechanical means.
Erosion/Weathering	Changes in color or texture brought about by continued environmental exposure (e.g., wind, sun, rain, snow, frost, etc.)

NOTE: Cracking, a break in the paint film going to the substrate having length but negligible width and checking, a break in the top coats of the paint film but not to the substrate having length but negligible width are not considered to be distresses for PAINTER EMS since the paint film is providing protection for the substrate. If a crack or check becomes wide enough to visually expose the substrate or an underlying coat, it becomes either peeling or lifting distresses.

Table 5. Substrate deterioration distresses.

Substrate Type	Deterioration Distress
Steel, iron, galvanized steel	Rust
Wood & wood products	Swelling, warping, surface weathering, rot, and delamination
Concrete	Spalling & exposed rebar
CMU, brick, ceramic tile, stucco	Spalling, chipping, cracking
Aluminum	Pitting
Polymers	Ultraviolet degradation
Glazing compound	Detached compound, missing material

4 PAINTER EMS Condition Assessment

Condition Survey Process

The coating condition survey is the process an inspector uses to collect the information necessary for determining the paint condition, condition index, and M&R cost estimates. The condition survey process was developed in conjunction with the CCI to evaluate and test the CCI using real situations. Appendix C contains a sample inventory collection worksheet. The more accurate the inventory database is, the better the calculated condition indexes will reflect true paint conditions.

Distresses are rated by percentage of total area affected. That total area affected by paint distresses is either (1) the actual area of a defect when the defects are isolated on the surface and are therefore easily measured, (2) the total area encompassing the defects when the concentration of defects within a given area is so high that individual measurements are impractical or, in essence, the entire area is affected by them, or (3) a combination of both.

To simplify the percentage estimation by an inspector and to improve the consistency between inspectors for the same distress evaluations, the percentage rating scheme used by the CAPP® System, a computerized paint management system developed by KTA-Tator, Inc., was determined as the best means. The CAPP® System percentage ratings are derived from specially prepared photographic standards based on the ASTM D-610 and *SSPC Guide to Visual Standard No. 2*, which are standards for evaluating the degree of rusting on painted surfaces. Instead of using the numerical rust grade ratings 1 through 9, however, it substitutes the ratings of A, B, and C described in Table 6.

When conducting the paint condition survey, the paint inspectors estimate the extent of distresses. The percentage of paint film distresses and of exposed substrate distresses are estimated relative to the component's total painted surface area. Estimates of the percentage of deteriorated substrate distresses are based on percentages of the exposed substrate only, rather than the total surface of the component. For example, a steel door with a film distress grade code of B has 1 to 3 percent of the paint deteriorating, an exposed substrate distress code of B+ indicates there is 0.3 to 1 percent bare steel exposed, and a deteriorated substrate distress code of C- indicates that 33 to 100 percent of the exposed steel is rusted. Appendix D contains a sample inspection form.

A condition survey is conducted by first evaluating any appearance distresses from a distance of 30 to 50 ft away from the face of the building being inspected. The inspector first evaluates whether the paint on the face is uniform in appearance. If the paint is uniform, the inspector marks the *yes* block and goes on to the paint film evaluation. If it is not uniform, the inspector marks whether the contrast in

Table 6. Condition survey distress grades.

Distress Grade	Distress Percentage	Corresponding ASTM D 610 Rust Grades
A+	0 – 0.03%	9 – 10
A	0.03 – 0.1%	8
A–	0.1 – 0.3%	7
B+	0.3 – 1%	6
B	1 – 3%	5
B–	3 – 10%	4
C+	10 – 17%	3
C	17 – 33%	2
C–	33 – 100%	0 - 1

appearance is due to soiling or chalking only. The inspector then determines for both high and low contrast whether it is localized or widespread and the overall percentage of each severity level using the distress grade notation (A to C) from Table 6.

The inspector then performs a close-up evaluation of the face for the presence of paint film distresses, exposed substrate, and deteriorated substrate for each component item making up the face or section. The distress grade percentage code (A to C) is noted for each distress type for each item. If the deteriorated substrate requires replacement, there is an optional space on the form to note the quantity needed. Finally, for each component item there is a check box to indicate whether the distresses are localized or widespread. There is also a *Remarks* section for identifying component-specific information such as a missing louver from a vent cover, a missing piece of siding, etc., and a *Notes* section for identifying other building-specific distress information.

Deduct Value Determination

A *deduct value* is a quantity deducted from the maximum possible condition index (100) to account for the presence of a distress. The more distresses present or the higher the distress severity, the greater the deduct value will be. The deduct value curves for paint film were developed by first breaking maintenance painting down into seven levels (Table 7), based on work effort to correspond to the seven general condition descriptions (Table 1).

Paint experts used the maintenance action descriptions to develop deduct value curves based on their combined experience. Deduct value curves were developed for several common substrates used for exterior construction on Army bases. These curves were developed by determining at what percentage of film distress maintenance should be performed (a deduct value of 60), what percentage constituted failure (a deduct value of 90), where zero percent and 100 percent film distress fit on a curve, and other substrate specific points. The same process was then performed for exposed substrate when 100 percent of the film deterioration is exposed substrate, and again for deteriorated substrate when 100 percent of the exposed substrate is deteriorated. Once

Table 7. Maintenance level work effort for paint film distresses.

Maint. Level	Condition Index Range	Visible Distresses	Maintenance Action
1	86 - 100	Essentially None	No work to do
2	71 - 85	Very Slight	No work necessary
3	56 - 70	Slight	Localized touch-up advised, but not necessary* • Spot cleaning and surface preparation employed • Preparation can be accomplished by hands on methods • Paint Systems applied to localized areas
4	41 - 55	Moderate	Localized to wide-spread touch-up recommended* • Spot to wide-spread cleaning and surface preparation employed • Preparation may require power equipment • Paint systems applied to localized or wide-spread areas
5	26 - 40	Significant	Widespread painting recommended • Wide-spread cleaning and surface preparation employed • Preparation should require the use of power tools or other mechanical methods • Paint systems applied to widespread areas
6	11 - 25	Overall	Total painting required • Extensive cleaning and surface preparation employed • Preparation requires the use of power tools or other mechanical methods • Paint systems applied to entire area
7	0 - 10	Overall	Near total paint removal and replacement required • Complete cleaning and surface preparation employed • Preparation requires the use of power tools or other mechanical methods to remove most, if not all, paint • New paint system completely applied

* Note that touch-up will not achieve a CCI of 100 because of the resulting appearance contrast. Whenever touch-up painting is performed, some color contrast will exist because of aging and tint variations with the new and old paint on the surface.

those points were identified a smooth curve was drawn through them, thus designating the remainder of the points from A+ to C-. The curves were evaluated and adjusted through field tests at several military installations.

The deduct value curves for appearance distresses were developed in much the same way as those for film distresses. The CCI development team of paint experts

determined how they would classify the paint condition based on the presence of different appearance distresses and assigned a deduct value for those conditions. They assigned deduct values for distresses covering 100 percent of a surface, and at what extent they recommended some maintenance be performed. The points were plotted and a smooth curve was drawn through the points.

The mathematical equations for the film deduct value curves were determined using least squares regressions according to the following criteria: they must be (1) continuous between 10^{-4} percent and the percentage value where they reached a maximum, i.e., 90 for film deterioration on wood, 100 for deteriorated wood substrate, etc., (2) less than 0.4 at an A+ rating, and (3) reach the maximum deduct value on the table between zero percent and 100 percent. Equation 4 occurred for all instances with good correlation to the expert generated data points.

$$\ln DV = a + b \ln x + \frac{c}{x} \quad \text{[Eq 4]}$$

DV is the deduct value and x is the percentage of area affected by the distress. Appendix A contains curves for the various substrates showing each distress level, a list of the a, b, and c values for the equation for each substrate and distress level, and a lookup table based on that equation.

The film deduct value curves were modified to reflect the presence of lead in the paint system. A common equation form was derived in the same manner as for nonlead-containing paint:

$$\frac{1}{dv} = \frac{A + D \log X + C \log X}{X} \quad \text{[Eq 5]}$$

Appendix H contains curves for the various substrates showing each distress level, a list of the a, b, and c values for the equations for each substrate and distress level, and a lookup table based on that equation. Appendix B shows the curves for appearance deduct valves and a list of the a, b, c, d, and e values for the equation, and a lookup table based on:

$$DV = a + bx + c\sqrt{x}\ln x + d\sqrt{x} + e\ln x \quad \text{[Eq 6]}$$

For percentage values less than 10^{-4} percent, the deduct values are defined by the equation:

$$DV = 0 \quad \text{[Eq 7]}$$

For percentages equal to or greater than 66.67 percent, the deduct value equation is:

$$DV = V_M \qquad \text{[Eq 8]}$$

where:

V_M = the deduct value at 66.67 percent.

Development of Photographic Standards

To increase the efficiency of the condition survey process and to promote better reproducibility between inspectors, photographic standards for coating condition were developed. Several hundred photographs were taken of walls, doors, windows, eaves, and crawl space skirts. The photos were rated by the CCI development team according to the degree of distresses depicted. Photos depicting examples of buildings with uniform paint appearance, low contrast and high contrast paint appearance, and middle of the A, B, and C ranges for paint film deterioration were selected as the visual condition standards. An initial booklet of photographic standards was assembled.

Eight buildings at Fort Riley, KS, were then inspected by three college students to discover any deficiencies in the condition survey procedure or the photographic standards. The only concern expressed by the students was a lack of clarity in the definitions of "localized" and "widespread" distress. Consequently, the CCI development team revised those definitions. A few weeks later, the same buildings were evaluated by the members of the CCI development team. The steps at Building 7054 had been painted sometime after the students inspected them, but otherwise all buildings were in the same condition during the second inspection.

Appendix F summarizes the data collected on the eight buildings. It contains a listing of the inventory items for each face and the ratings by each inspector. The appendix also provides an overall CCI summary of each face and a breakdown of the condition indexes calculated for each face and building based on each inspector's input.

As a result of these evaluations, it was recommended that the photographic standards be modified to include (1) a more thorough written explanation of each photograph and (2) photographs depicting both localized and widespread distresses. It is anticipated that the final photographic standards developed in this study will be included in a PAINTER Inspection and Distress Manual.

5 Coating Condition Index Calculations

Determining the Paint Appearance Index

The Paint Appearance Index (PAI) is based on the presence of visible contrast on a painted face of a structure when viewed from a distance of 30 to 50 ft. The equation for determining the PAI is:

$$PAI = 100 - (DV_{max} + 0.05 \times DV_{min}) \quad \text{[Eq 9]}$$

where DV_{max} is the maximum deduct value of the two severity level appearance values, and DV_{min} is the other one. In cases where there is only one severity level present, a 1.0 deduct value is used for the nonexistent value. In the case of a uniform appearance, the 1.0 deduct value is used for both the DV_{max} and the DV_{min}.

Determining the Paint Film Index

The PFI is a value dependent upon the type of substrate painted, the percentage of paint film deterioration occurring, the percentage of substrate exposed, and the percentage of the exposed substrate that is deteriorated. Appendixes A and H list deduct values for substrate types commonly used for construction. (Appendix A for nonlead-containing paints and coatings and Appendix H for those containing lead-based paint.) They correspond to the condition survey rating codes for the various distresses. Table 8 lists the correction factors for the different combinations of paint film deterioration and exposed substrate percentages. Table 9 lists the weighting values used when combining the different types of distresses.

Table 8. Exposed substrate correction factors.

	Exposed Substrate								
Film Deteriorations	**A+**	**A**	**A-**	**B+**	**B**	**B-**	**C+**	**C**	**C-**
A+	1	1	1	1	1	1	1	1	1
A	0	1	1	1	1	1	1	1	1
A-	0	0.333	1	1	1	1	1	1	1
B+	0	0.1	0.3	1	1	1	1	1	1
B	0	0.033	0.1	0.333	1	1	1	1	1
B-	0	0.01	0.03	0.1	0.3	1	1	1	1
C+	0	0.006	0.018	0.059	0.176	0.588	1	1	1
C	0	0.003	0.009	0.03	0.091	0.303	0.515	1	1
C-	0	0.001	0.003	0.01	0.03	0.1	0.17	0.33	1

Table 9. Substrate distress weighting values.

Survey Rating Code	Rating Weighting Value
A+	0.0003
A	0.001
A–	0.003
B+	0.01
B	0.03
B–	0.1
C+	0.17
C	0.33
C–	1.0

The PFI is calculated by determining the Paint Film Deduct (PFD) value. The PFD reflects the impact of the paint film distresses and amount of exposed substrate present by the equation:

$$PFD = DV_F + [(DV_E - DV_F) \times C] \qquad \text{[Eq 10]}$$

where DV_F is the film deterioration deduct value from Appendix H corresponding to the condition survey film deterioration rating code, DV_E is the exposed substrate deduct value from Appendix H corresponding to the condition survey exposed substrate rating code, and C is the exposed substrate correction factor from Table 8.

The total film deduct (TFD) value includes the impact of any deteriorated substrate that may be present on the painted surface. It is calculated by the equation:

$$TFD = PFD + [(DV_S - PFD) \times W_S] \qquad \text{[Eq 11]}$$

where DV_S is the deteriorated substrate deduct value from Appendix H corresponding to the condition survey deteriorated substrate rating code, and W_S is the substrate distress weighting value from Table 9 corresponding to the condition survey deteriorated substrate rating code. The Item Condition Index (ICI) is determined by the equation:

$$ICI = 100 - TFD \qquad \text{[Eq 12]}$$

Once the ICI has been calculated for each item comprising the face of a structure, the item indexes are combined into the PFI using the area of each item as a weighting factor, as indicated by the equation:

$$PFI = \sum_{i=1}^{k} ICI_i \times \frac{A_i}{A_T} \qquad \text{[Eq 13]}$$

where i is an item of the face, k is the total number of items for the face, A_i is the item area, and A_T is the total area of all items.

CCI Determination

The PAI and PFI are combined into a Face Condition Index (FCI), depending on which of the following conditions are indicated by the PFI and the PAI calculations.

When the PFI > 70:

If $PAI > 70$,	the FCI	= 0.99 x PFI or 70,	whichever is greater
If $40 < PAI \leq 70$,	the FCI	= 0.95 x PFI or 70,	whichever is greater
If $25 < PAI \leq 40$,	the FCI	= 0.90 x PFI or 70,	whichever is greater
If $PAI \leq 25$,	the FCI	= 0.85 x PFI or 70,	whichever is greater.

When the PFI ≤ 70:

If $PAI > 70$,	the FCI	= 1 x PFI
If $40 < PAI \leq 70$,	the FCI	= 0.98 x PFI
If $25 < PAI \leq 40$,	the FCI	= 0.95 x PFI
If $PAI \leq 25$,	the FCI	= 0.90 x PFI.

The CCI is the weighted average of the FCIs, calculated by the equation:

$$CCI = \sum_{j=1}^{m} FCI_j \times \frac{A_j}{A_T} \quad \text{[Eq 14]}$$

where:

j = the face of a building or structure
m = the total number of faces in the structure
A_j = the painted area of the face
A_T = the total building area that is painted.

Example CCI Calculation

Suppose the exterior of a family housing unit has wood siding. The North and South wall areas are 80 sq ft each and the East and West walls are 72 sq ft each. There is a 21 sq ft steel personnel door in the East wall, a wood one in the West wall and a 3 x 3 ft (12 linear feet) aluminum frame window in both the North and South walls. Everything is painted; the doors and windows using lead-based paint.

Condition Survey Results

North Wall:

The appearance of the wall was uniform. The film deterioration on the wall was A and the exposed substrate and deteriorated substrate were both A+. The window frame had A+ film deterioration and A+ for glazing compound.

West Wall:

The appearance portion showed that the wall was Not Uniform. It had a localized high contrast rating of A- and a widespread low contrast rating of A. The film deterioration on the wall was B+ with the exposed substrate an A and deteriorated substrate an A+. The door ratings were B- for film deterioration, B+ for exposed substrate and C- for deteriorated substrate.

South Wall:

The appearance portion showed that the wall was Not Uniform. It had a widespread high contrast rating of B. The film deterioration on the wall was B with the exposed substrate an A- and deteriorated substrate an A+. The window frame had A film deterioration, A+ for both exposed substrate and deteriorated substrate. The window glazing compound was rated as A- for all distress levels.

East Wall:

The appearance portion showed that the wall was Not Uniform. It had a localized high contrast rating of A- and a widespread low contrast rating of A. The film deterioration on the wall was B with the exposed substrate a B+ and deteriorated substrate an A+. The door ratings were B for film deterioration, B+ for exposed substrate and C- for deteriorated substrate.

CCI for the Building Exterior

North Face of the building:

The deduct value for the appearance is 1 (Table B2, Appendix B)

The deduct value for the wall paint deterioration is 4.8 for film deterioration and 0 for other distress levels (Table A2, Appendix A)

The deduct value for the window frame paint is 0 for all distress levels (Table H5, Appendix H)

The deduct value for the painted glazing compound is 0 for all distress levels (Table H8, Appendix H)

From Equation 9:

$$PAI = 100 - (1 + 0.5 \times 1)$$
$$PAI = 98.5$$

For the Wall Component from Equation 10:

$$PFD = 4.8 + [(0 - 4.8) \times 0]$$
$$PFD = 4.8$$

From Equation 11:

$$TFD = 4.8 + [(0 - 4.8) \times 0.0003]$$
$$TFD = 4.79856$$

From Equation 12:

$$ICI = 100 - 4.80$$
$$ICI = 95.2$$

For the Window Component:

PFD = 0 + [(0 – 0) x 0]
PFD = 0
TFD = 0 + [(0 – 0) x 0.0003]
TFD = 0
ICI = 100 – 0
ICI = 100

For the Window Glazing Component:

PFD = 0 + [(0 – 0) x 0]
PFD = 0
TFD = 0 + [(0 – 0) x 0.0003]
TFD = 0
ICI = 100 – 0
ICI = 100

For the North Face from Equation 13:

PFI = 95.2 x 80/104 + 100 x 12/104 + 100 x 12/104
PFI = 73.231 + 11.538 + 11.538
PFI = 96.3

Since the PFI > 70 and the PAI is > 70,

FCI = 0.99 x 96.3
FCI = 95.3

West Face of the building:

The deduct value for the localized high contrast appearance is 31.8 (Table B2, Appendix B)
The deduct value for the widespread low contrast appearance is 12.9 (Table B2, Appendix B)
The deduct value for the wall paint deterioration is 41.8, for the exposed substrate is 8.4, and for deteriorated substrate is 0 (Table A2, Appendix A)
The deduct value for the paint on the door is 90 for film deterioration, 89.9 for exposed substrate and 100 for deteriorated substrate (Table H2, Appendix H)

PAI = 100 – (31.8 + 0.5 x 12.9)
PAI = 61.75

For the Wall Component:

PFD = 41.8 + [(8.4 – 41.8) x 0.1]
PFD = 38.46
TFD = 38.46 + [(0 – 38.46) x 0.0003]
TFD = 38.4485
ICI = 100 – 38.45
ICI = 61.55

For the Door Component:

PFD = 90 + [(89.9 - 90) x 0.1]
PFD = 89.99
TFD = 89.99 + [(100 – 89.99) x 1]

TFD = 100
ICI = 100 – 100
ICI = 0

For the West Face:
PFI = 61.55 x 72/93 + 0 x 21/93
PFI = 47.652 + 0
PFI = 47.7

Since the PFI > 70 and the PAI is > 70,
FCI = 0.98 x 47.7
FCI = 46.7

South Face of the building:
The deduct value for the widespread high contrast appearance distresses is 59 (Table B2, Appendix B)
The deduct value for the low contrast appearance distresses is 1 since there was none noted
The deduct value for the wall paint deterioration is 55.4, for the exposed substrate is 31, and for deteriorated substrate is 0 (Table A2, Appendix A)
The deduct value for the window frame paint is 16.7 for deteriorated paint and 0 for the other distress levels (Table H5, Appendix H)
The deduct value for the painted glazing compound is 16.7 for film deterioration and exposed substrate and 33.6 for deteriorated substrate (Table H8, Appendix H)

PAI = 40.5

For the Wall Component from Equation 10:
PFD = 52.06
TFD = 52.044
ICI = 48.0

For the Window Component:
PFD = 16.7
TFD = 16.695
ICI = 83.3

For the Window Glazing Component:
PFD = 16.7
TFD = 16.751
ICI = 83.2

For the South Face:
PFI = 56.1
FCI = 55.0

East Face of the building:
The deduct value for the localized high contrast appearance distresses is 31.8 (Table B2, Appendix B)

The deduct value for the widespread low contrast appearance distresses is 12.9 (Table B2, Appendix B)
The deduct value for the wall paint deterioration is 55.4, for the exposed substrate is 52.4, and for deteriorated substrate is 0 (Table A2, Appendix A)
The deduct value for the paint on the door is 100 for film deterioration, 90 for exposed substrate and 100 for deteriorated substrate (Table H3, Appendix H)

PAI = 61.75

For the Wall Component:

PFD = 55.1
TFD = 55.08
ICI = 44.9

For the Door Component:

PFD = 96.67
TFD = 100
ICI = 0

For the East Face:

PFI = 34.77
FCI = 33.0

The CCI for the exterior of the building from Equation 14:

CCI = 55 x 80/304 + 33 x 72/304 + 46.7 x 80/304 + 46.7 x 72/304
CCI = 14.47+ 7.82 + 12.29 + 11.06
CCI = 58.4

6 PAINTER EMS Engineering Tools

PAINTER EMS Condition Prediction Models

Like all EMSs, PAINTER uses past performance in conjunction with present condition to predict future component deterioration trends. The more data that can be acquired on past performance, the better the future condition prediction will be.

Paint is a mixture composed of solid coloring matter or pigment suspended in a liquid medium, typically a binder such as alkyds, vinyls, or epoxies and solvent, which is applied as a coating to various types of surfaces for decorative, protective, or other functional purposes. In addition to the pigment, binder, and solvent, a paint formulation may also contain many additives, such as defoamers, thickeners, flow agents, catalysts, wetting agents, and plasticizers to improve various paint properties. A paint system's life may vary depending on many factors: the paint's contents, the compatibility of materials in the paint during and after drying, the surface preparation and environmental conditions when it was applied, and the environment it is exposed to in use. If good adhesion occurs between coats, the significant degradation can only occur from the atmospheric side of the film or the substrate side, especially if inadequate surface preparation was performed.

Each source of degradation will have its own mechanism and thus its own rate. An expected degradation rate will occur from the atmospheric side of the paint film. In addition, another may occur from the substrate side if surface preparation is inadequate or the paint system is incompatible with the substrate. If adhesion problems exist between coating layers or other paint components, yet another deterioration mechanism is added to the system and the degradation rate will increase. These degradation mechanisms continue and are not normally detectable until a visible change occurs in the coating film. PAINTER classifies this visible change as a distress.

Since paint deterioration is so complex, very little has been published in literature attempting to model it. Literature searches as well as telephone interviews were conducted to determine what research has been performed by other organizations. One model, which deals exclusively with rust development on painted steel substrates, was identified as consistent with PAINTER EMS methodologies. The model states that, for coated steel, the paint condition stays constant at or near rust rating of 10 for a threshold or induction period of several years during which no rust is observed and then begins to deteriorate linearly at a rate between 0.5 and 1.0 rust ratings per year (Figure 1) (Appleman 1985). No models were found for nonsteel substrates. Studies of organic paints and coatings on concrete, lightweight concrete, brickware, and renderings paint deteriorates on the southern facades from 1.2 to 1.8 times faster than on northern walls during the first 10 years after painting (Rautiainen 1984, pp 329-339).

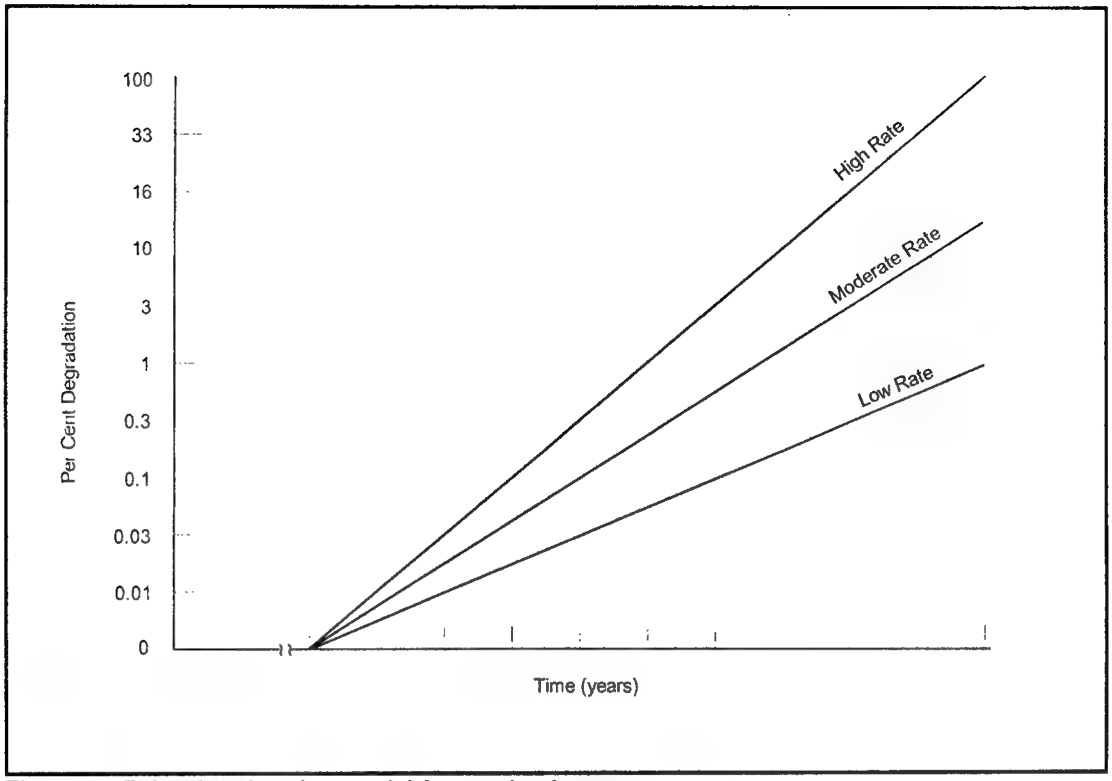


Figure 1. Paint deterioration model for steel substrates.

As a first approximation for a PAINTER EMS Deterioration Model, until data can be collected to refine the equations, the Appleman model is used. Since ferric metals rust within a matter of hours after exposure to the atmosphere, the amount of rusting is essentially the amount of exposed substrate and, in many instances, closely approximates film deterioration. As rusting continues, some film undercutting occurs. Since paint film undercutting caused by substrate deterioration that occurs for steel also holds true for galvanized steel and wood substrates, a logarithmic deterioration rate similar to that for steel should also hold true for them. Since there was no data available for the deterioration of paints and coatings on other substrates, the same general model is used.

Appearance is a combination of the coating system condition and other external factors. Things that affect appearance are paint film condition (e.g., peeling, blisters, chalking, fading, abrasion, checking, etc., surface adhesion of things such as dirt, tire marks, bird droppings, rust stains, etc.), parasitic attack (e.g., mildew, wood bores, termite tunnels, vines, etc.), and construction problems (e.g., missing siding, spilled paint or roofing tar, holes or gaps, broken windows, color choices, etc.). Since after a certain point the paint film condition overrides the appearance condition, the appearance condition deterioration model follows that of the film deterioration model.

The prediction of future CCI values using these models requires a minimum of two inspections. From the two inspection points, the film deterioration rate is determined assuming the linear relationship (Figure 1). The same is done for the exposed substrate, deteriorated substrate, and appearance. Once the projected deduct value for a future date is determined for each component of the condition index, the future

condition index and a cost associated with it can be calculated based on the appropriate tables.

Initially, as PAINTER is used at an installation, there will only be one inspection data point for prediction purposes. When there is only one data point to use, a good approximation of where the induction time ends and deterioration begins is to divide the current coating life by two and use that as a first point for steel, galvanized steel, and wood. For other substrates, since the deterioration rate is normally less than that of steel and wood, divide by three and subtract that value from the current paint system life. For example, suppose a 5-year old paint system on a wood wall were inspected and found to have a distress rating of B+. If previous inspections were not performed, the induction time would be 2.5 years. The extension of a straight line between a distress rating of A+ at 2.5 years and B+ at 5 years would provide a rating prediction for future years and a basis for calculating a future CCI.

PAINTER EMS Economic Analysis Procedures

The cost analysis procedure for PAINTER EMS is based on the most current paint inspection results and an estimate for performing M&R based on the current condition. In performing a paint inspection for PAINTER, the general appearance is evaluated first, followed by the film inspection.

Several inferences can be drawn from the appearance information collected: (1) if the appearance is uniform, there is no paint maintenance required; (2) if the appearance is nonuniform, but the nonuniformity is due to mildew, chalking, or dirt only, paint maintenance requirements consist of washing only; and (3) if the appearance is low–contrast nonuniformity because of things other than mildew, chalking, or dirt, paint maintenance requirements consist of some surface preparation and an application of a partial finish coat. If, however, the appearance is high–contrast nonuniformity because of things other than mildew, chalking, or dirt (implying areas of exposed undercoat and/or substrate and possibly deteriorated substrate), the paint maintenance requirements are more complex. When high contrast paint distresses exist, one of the M&R actions described in Appendix E (Table E-1) is necessary.

The paint film inspection is a close-up inspection for specific distresses. The area (A+ thru C- percentage code) and extent (localized or widespread) of identified distresses are recorded. Painting M&R cost estimates can then be determined based on the inspection report.

The surface preparation options depend on substrate and CCI. Table E-2 gives a comparison of typical surface preparation methods projected for use with specific CCI ranges. Table E-3 lists surface preparation options recommended for use with the different types of substrate.

PAINTER M&R costs are determined based on the square footage of work to be done. These costs are calculated based on labor costs published by the R.S. Means Company,

Inc. (1992) and work production rates published by the Paint Decorators and Contractors of America. Labor–associated costs are determined by:

$$C_i = p(R_m + OH_v + OH_f) \qquad \text{[Eq 15]}$$

where:

C_i = the total labor cost per hour for an activity
R_m = the national mean labor rate with fringe benefits for 1992 published by R.S. Means Company
OH_v = a variable overhead rate
OH_f = a fixed overhead rate p = a profit index.

A 10 percent variable overhead rate, 55 percent fixed overhead, rate and a 20 percent profit index was used in calculating labor costs.

Table E-4 lists the surface preparation labor costs per square foot for a variety of surface preparation methods. The national mean glaziers labor rate is used for glazing, the mean common building laborer labor rate is used for cleaning and washing, and the mean air tool labor rate is used for abrasive blasts. The abrasive blast rate is based on use of a 7/16-in. venturi type long barrel nozzle, 315 cu ft of air per minute at 100 psi pressure. It is also based, for steel substrates, on the existing coating being blistered and the steel rusting with some hard scale.

Tables E-5 and E-6 list the cost per square foot for brush and roller painting for a variety of different substrates. The mean structural steel painters labor rate is used for painting steel, pipe/conduit, and machinery/equipment. The mean ordinary painter labor rate is used for all other substrates and components. Table E-7 lists the costs per square foot for painting those substrates using a spray gun. The labor costs are calculated using the mean spray painter labor rate for all substrates.

Table E-8 lists typical costs per square foot for paint and coating materials. These costs are based on the 1992 GSA catalog prices. Sand blast abrasive costs are based on material costs published by the R.S. Means Company (1992).

Table E-9 lists the cost per square foot of siding materials, which is based on the home improvement estimates published by the R.S. Means Company. Table E-10 lists correction factors by state for the various labor rates published by the R.S. Means Company. The labor cost to perform the M&R is corrected to account for geographical locations by using the following formula:

$$C_{Ci} = kC_i \qquad \text{[Eq 16]}$$

where:

C_{Ci} = the geographically corrected labor cost for an activity
k = the state correction factor
C_i = the uncorrected labor cost.

To calculate the painting maintenance and repair costs associated with the different scenarios, the following equations were developed. The various scenarios are listed below followed by the equations to calculate the M&R costs.

1. For building faces with localized mildew, chalking, and/or dirt only:

$$C_T = C_W A_S \qquad \text{[Eq 17]}$$

where:

C_T = the total M&R cost
C_W = the unit cost for washing or scrubbing
A_S = the area covered by mildew, chalking, and/or dirt.

2. For building faces with widespread distribution of mildew, chalking, and/or dirt only:

$$C_T = C_W A_T \qquad \text{[Eq 18]}$$

where:

A_T = the total surface area.

3. For building faces with localized paint distresses having low contrast with the surrounding areas:

$$C_T = (C_{Ms} + C_S + C_{Mp} + C_P) A_F \qquad \text{[Eq 19]}$$

where:

C_{Ms} = the cost of surface preparation materials if the surface preparation requires abrasive blasting
C_S = the labor cost for surface preparation
C_{Mp} = the cost of coating material
C_P = the cost for applying the coating
A_F = the area of film deterioration.

Note that applying a partial finish coat will result in a low color contrast. The user may want to apply a full finish coat to eliminate any color contrast, in which case equation 20 will apply. PAINTER will provide both cost calculations and allow the user to select the desired option based on the cost differential.

4. For building faces with widespread paint distresses having low contrast with the surrounding areas:

$$C_T = (C_{Ms} + C_S) A_F + (C_{Mp} + C_P) A_T \qquad \text{[Eq 20]}$$

5. For building faces with high contrast, localized paint distresses due to both exposed and deteriorated substrate:

$$C_T = C_N A_D + (C_{Ms} + C_S)(A_E - A_D) + (C_{Mp} + C_P) A_E + (iC_{Mp} + nC_P) A_F \qquad \text{[Eq 21]}$$

where:

C_N = the estimated replacement cost of the deteriorated material
A_D = the area of deteriorated substrate
A_E = the area of exposed substrate
n = the correction factor for application of multicoats of coating material
i = the number of top coats to be applied.

Note that applying a partial finish coat will result in a low color contrast. The user may want to apply a full finish coat to eliminate any color contrast, in which case equation 22 will apply. PAINTER will provide both cost calculations and allow the user to select the desired option based on the cost differential.

6. For building faces with high contrast, localized paint distresses due to only exposed substrate:

$$C_T = (C_{Ms} + C_S + C_{Mp} + C_P)A_E + (iC_{Mp} + nC_P)A_F \qquad \text{[Eq 22]}$$

Note that applying a partial finish coat will result in a low color contrast. The user may want to apply a full finish coat to eliminate any color contrast, in which case equation 23 will apply. PAINTER will provide both cost calculations and allow the user to select which option is desired based on the cost differential.

7. For building faces with high contrast, localized paint distresses due only to exposed undercoat:

$$C_T = (C_S + iC_{Mp} + nC_P)A_F \qquad \text{[Eq 23]}$$

Note that applying a partial finish coat will result in a low color contrast. The user may want to apply a full finish coat to eliminate any color contrast, in which case equation 24 will apply. PAINTER will provide both cost calculations and allow the user to select the desired option based on the cost differential.

8. For building faces with high contrast, widespread paint distresses due to both exposed and deteriorated substrate:

$$C_T = C_N A_D + (C_{Ms} + C_S)(A_E - A_D) + (C_{Mp} + C_P)A_E + (iC_{Mp} + nC_P)A_T \qquad \text{[Eq 24]}$$

9. For building faces with high contrast, widespread paint distresses due to only exposed substrate:

$$C_T = (C_{Ms} + C_S + C_{Mp} + C_P)A_E + (iC_{Mp} + nC_P)A_T \qquad \text{[Eq 25]}$$

10. For building faces with high contrast, widespread paint distresses due only to exposed undercoat:

$$C_T = (C_S + iC_{Mp} + nC_P)A_T \qquad \text{[Eq 26]}$$

PAINTER EMS Prioritization and Optimization Models

The coating condition index combines with the condition prediction models to form the basis for the PAINTER EMS M&R prioritization and optimization models. As a coating system ages, it deteriorates and the M&R costs for restoring it to excellent

condition increase. Initially that cost is very low or nonexistent, but at some "trigger point," distresses develop in the system, and the rise in costs begins to accelerate. For example, for the first 2 or 3 years, a painted, galvanized steel building looks great. After 3 years, it will begin chalking and showing some dirty spots. Soldiers constantly brushing up against the building will rub off some of the chalked paint. After 5 years, the primer starts showing through where it has been rubbed and after 7 years, the galvanizing will show through. Four years later, rust will start to develop on the bare galvanized steel. The M&R costs are zero for the first 3 years and remain low until the bare galvanizing begins to appear. At that point, the M&R cost begins increasing at a faster rate. When rust begins, the cost rises accelerate (Figure 2). This means that, after remaining fairly level for 4 years, the M&R costs begin to escalate significantly for all years following year nine. Optimized M&R should be performed at year nine—the trigger point in the M&R optimization model for that building.

Due to budget restraints, manpower restraints, priority restraints and the like, much of the M&R performed will not be conducted at the trigger point. In most instances, it will be delayed several years, creating a penalty cost, which is the difference between the cost to perform M&R and what the cost would have been had it been performed at the trigger point. For the above example, if the M&R had been performed in year 12, there would be a penalty cost of $1.474 - $0.931, or $0.543 per sq ft of wall area (Figure 3).

The ratio of the planned M&R cost to the trigger point cost provides a Penalty Index. In the above example for M&R planned in year 12, the Penalty Index is $1.474 ÷ $0.931, or 1.58. The 3-year M&R delay will cost 1.58 times as much to perform as at the trigger point.

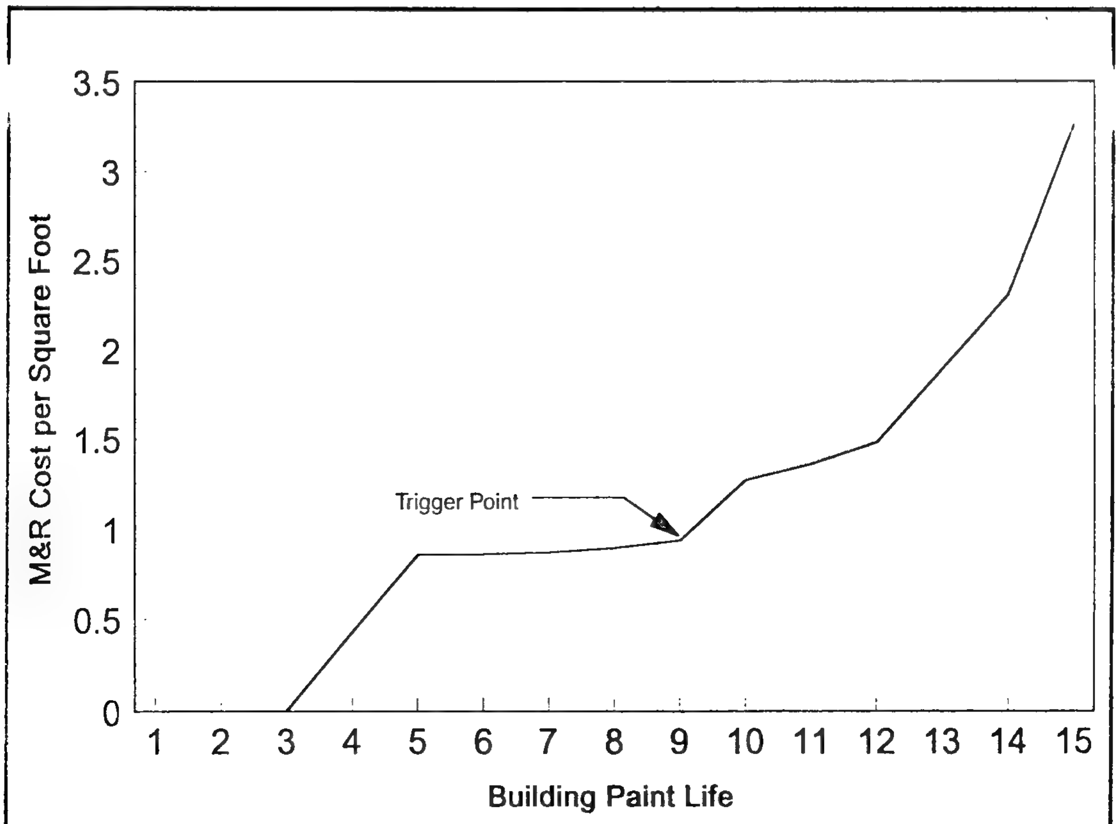


Figure 2. Paint life versus M&R cost example.

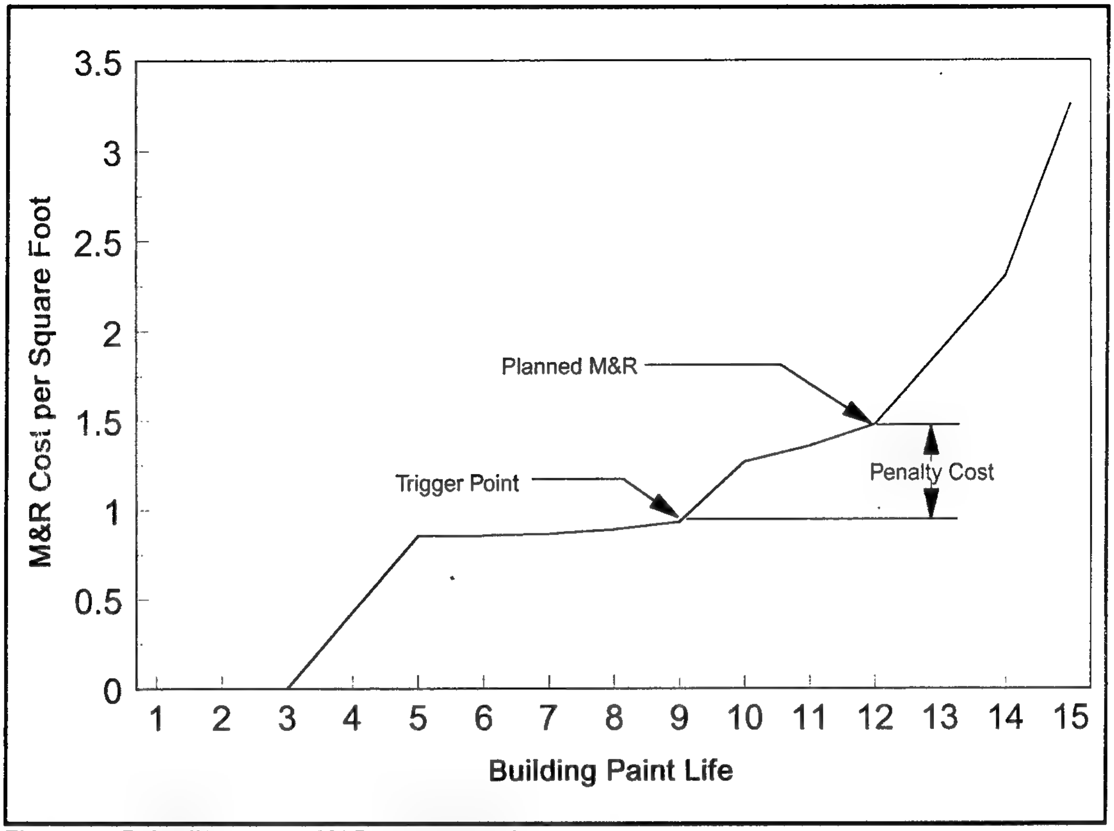


Figure 3. Paint life versus M&R cost example.

PAINTER EMS M&R prioritization may be based on any of several options. The options include CCI values (e.g., penalty cost, or penalty index), starting with the lowest CCI and working toward the highest. In conjunction with these are budgetary and manpower constraints.

PAINTER EMS M&R Management Tools

Project Level Management

The purpose of Project Level Management is to identify individual management units for improvements and any paint problems that need to be addressed during those improvements. It further assists in the development of project level M&R plans by developing and optimizing the M&R alternatives. Once optimal alternatives are selected, a project level M&R plan is developed. The plan is short term, usually 1 to 2 years in duration, and is based on current inspection data and results.

Building Complex Level Management

Building Complex Level Management, the network level management scheme for buildings and structures, provides fiscal year budget projections rather than project projections. It identifies candidate management units, projects, or buildings for improvements. The building complex level management scheme ranks building complexes or building groups for development of budgeting projections and long-term

work plans. This is performed using current and future projected condition assessment. The Building Complex Level M&R Plan is long term, generally up to 10 years, and is based on the current and projected condition index vs. age. The condition index determines the M&R cost and when to optimally perform M&R. The plan is based on parameters such as the trigger point, priority schemes, and available funds.

A part of the building complex management philosophy is the ability to reduce the condition assessment process by performing assessment of sample management units rather than the entire population of management units. For the most part, buildings on a typical military installation vary too much to be able to use sampling techniques; they must be individually inspected. In instances where sampling techniques can be used, the detail of the sample inspection is the same as all other PAINTER inspections.

To perform inspection sampling techniques, each building within the sample group must: (1) have similar paint histories (to include the building age), (2) be the same type of construction, e.g., wood, galvanized steel, CMU, etc., and (3) have similar usage, e.g., family housing, motor pools, warehouse storage, etc.

The required number of maintenance units in the sample group to be inspected is based on Table 10 below. This sample size will provide 95 percent confidence that the inspection results can be applied to all maintenance units in the group.

Note: For buildings other than child-related facilities, if an inspector uses a laptop type computer during inspections with software capable of calculating the CCI on the spot, the above criteria may not be necessary. If, after inspecting five or six randomly selected buildings, the calculated CCIs do not vary by more than ±7 points from the mean, the building complex inspection requirements are complete. If there is greater variance, the inspection of the building complex should continue until it meets the above criteria.

Table 10. Inspection sample size based on number of maintenance units in group.

Number of Maintenance Units In Grouping	Number of Maintenance Units To Be Inspected
20	20
40	31
60	38
80	42
100	45
200	51
300	54
400	55
600	56
1000	57
>1000	58

PAINTER EMS M&R History

Army Regulation 420-70 (May 1992) requires that "Permanent records of painting will be maintained for each building or structure. Records will indicate date for each time painted, condition of surface, type of surface and surface preparation, specification number(s) of paint(s) used, number of coats of each type paint, and other pertinent data useful for assessing the performance of the coatings applied and in determining the compatibility of future paint coatings." Very few Army installations maintain good permanent paint records. In most instances, installations rely on old contracting records for painting data. PAINTER EMS will provide a tool for installations to comply with AR 420-70. Appendix F lists the paint history data maintained by PAINTER.

Lead-Based Paint Systems

The presence of lead-based paints on government-owned buildings is a major concern within the Department of Defense in general, especially in and around buildings and structures frequented by small children or by pregnant women. Such buildings include family housing, child development centers, family child care homes, schools, playgrounds, and similar facilities. Lead-based paint has been classified as a hazardous material and special requirements exist for its maintenance and disposal. Those requirements typically double or triple the cost of M&R wherever lead-containing paint is encountered.

The PAINTER EMS provides the installation manager information on where potential lead problems may exist by tracking a building or building component that contains lead-based paints. The presence of lead in paint does not affect the condition index value of non-child related facilities, but only identifies it to inform the manager that extra effort is involved with the M&R.

PAINTER maintains the following lead-based paint information for each building component or subcomponent: (1) the date when the component or subcomponent was tested for lead-containing paint, (2) the name of the inspector, (3) measured amount of lead content of the paint, (4) the method used to test for lead, (5) the equipment manufacturer and serial number, and (6) where within the paint film the lead, if found, was located. (Identification of equipment manufacturer and serial number is important due to reproducibility problems between pieces of test equipment, even test equipment from the same manufacturer.)

The measured amount of lead is compared by PAINTER with Housing and Urban Development (HUD) and Army policy guidelines and a risk evaluation is conducted for each component or subcomponent based on the lead survey results and the coating condition survey results. Appendix G contains a flow diagram for lead-based paint risk assessment and M&R guidelines based on the risk assessment.

Lead-based report codes were developed to indicate the presence or absence and condition of lead-based paints and indicate the risk assessment results. The code "NL" is used when a building has no lead, meaning that it has less than 0.5 percent by weight or 1.0 mg/cm of lead-based paint. The code "LI" is used when lead-based paint is present but intact. The code "LP" is used to flag deteriorating lead-based paint.

And, the code "ND" identifies buildings constructed or last renovated before 1978, where components have not had a lead survey and the presence of lead has not been determined.

7 PAINTER EMS Reports

PAINTER provides reporting capabilities to help installation managers assess all of the paint data and make decisions concerning paint M&R options for the installation. These reports provide the managers with recommendations and allow them to perform "What If" analyses. Discussions with DEH personnel and paint experts as well as developers of other USACERL EMSs have identified a list of desirable reports that PAINTER should be able to generate to assist the installation managers. A computerized version of PAINTER will offer them to users. A brief description of each report follows.

Work Plan Report

The Work Plan Report generates both short- and long-range M&R work plans.

10-Year CCI Prediction Report

The 10-year CCI Prediction Report provides the yearly projected appearance condition index, film condition index, and coating condition index for maintenance units for a period of 10 years.

Life-Cycle Cost Analysis Report

The Life-Cycle Cost Report computes the life-cycle cost for Cyclic Painting, PAINTER Recommended Painting, and other strategies and compares the life-cycle cost differences. It also computes the impact of delayed M&R on the life-cycle costs.

Building Deterioration Curve

The Building Deterioration Curve Report prints projected deterioration curves based on current and past inspection data.

Inspection Report

The Inspection Report is a printout of inspection results.

Inspection Form

The Inspection Form Report prints out PAINTER Inspection Forms and PAINTER Inventory Forms.

M&R Cost Estimate Report

The M&R Cost Estimate Report is a compilation of cost estimates to perform painting M&R on one or more buildings.

BMAR Elimination Plan (5-Year) Report

The BMAR Elimination Plan (5-Year) Report is a budget plan which, if an unconstrained budget were available, would eliminate the backlog of maintenance and repair projects for painting at an installation.

Data Base Sorting Report

The Data Base Sorting Report is a printout of user-defined information in the PAINTER database. The report can list buildings that have mold or chalking distresses only, the same substrate, lead-based paint, a specific type of paint, exposed or deteriorated substrate less than a specific value, specific components, a penalty index within a specified range and an appearance condition, and film condition or coating condition indices within a specified range. It can also include a list of building CCIs, building types, building sizes (with components), and buildings painted by year.

8 Painter EMS Training Requirements

Training requirements were identified for the use and implementation of the PAINTER EMS. The training program will:

1. Sell the use of PAINTER.

2. Define what PAINTER is and how it fits the needs of the DEH/DPW, including a step-by-step outline, from the pros and cons of using PAINTER to the paperwork involved in its use.

3. Define what reports will be generated to help the DEH/DPW.

4. Demonstrate how to prioritize the M&R requirements.

5. Define the implementation of PAINTER to include the tasks necessary for that implementation.

6. Address finances: the recurring annual inspection costs, how money should be allocated best, and the effects of delays in M&R.

Appendix I includes a draft training outline for PAINTER EMS. The training should be tailored to three levels: (1) the inspector, (2) the data processing/acquisition specialist, and (3) the EMS manager. Some training in all nine areas will be conducted for everyone, although the amount of detail will vary depending upon the training level. The inspectors will be trained with heavy emphasis on the PAINTER inventory, the visual inspection, and the evaluation procedure. The data processing/acquisition specialists will be trained to use PAINTER software, building complex level management, and project level management. The EMS manager training will emphasize building complex level management, project level management, and PAINTER implementation.

9 Summary and Recommendations

This report describes the development of PAINTER, an Engineered Management System for the maintenance and Repair of paints and coatings on military facilities. The system includes an inventory procedure, a condition assessment procedure, tools to assist installation managers in determining painting M&R requirements as well as optimizing and prioritizing those requirements, and reports for generating M&R work plans and life-cycle cost analysis.

The overall condition rating procedure is based on the Coating Condition Index. The CCI is composed of two separate condition ratings, the Appearance Condition Index and the Film Condition Index. These indices are the basic tools for the other PAINTER EMS engineering tools. The refinement of the CCI and development and description of the other tools are included in this report. Those other tools include condition prediction tools, economic analysis tools, prioritization and optimization models, project level management and building complex level management tools, and paint history. A variety of PAINTER reports are described and how PAINTER handles lead based paint records. Finally, this report identifies the need for PAINTER training and provides a draft training outline.

It is recommended that full scale field testing of PAINTER EMS be conducted followed by implementation at Army Installations. Research should be conducted to develop deterioration curves for the various paint condition families, i.e., latex paint on CMU for one, latex paint on wood for another, etc. Finally, PAINTER should be expanded to include interior paints and coatings.

Appendix A: PAINTER Film Distress Deduct Value Constants, Graphs, and Tables

Equation: $\ln y = a + b \ln x - c/x$, where:
a, b and c are as follows in the Table below.

Table A1. Film distress deduct value constants.

Substrate and Distress Level	a	b	c
Film deterioration on steel	3.976398	0.20072202	0.17003588
Exposed steel	4.06804	0.17578602	0.17738423
Rusted steel	4.379495	0.09969797	0.14835635
Film deterioration on wood	3.993822	0.12632325	0.13480498
Exposed wood	4.183446	0.099464649	0.1179691
Rotted/swelling wood	4.427645	0.061309703	0.12503084
Concrete / CMU / others	3.697977	0.19278675	0.11989552
Exposed galvanizing	4.077285	0.17243598	0.15244487
Rusted galvanized steel	4.282594	0.12757734	0.075055727
Pitted aluminum	4.295393	0.13281071	0.130188
Deteriorated plastics	4.223667	0.094018343	0.071179586
Missing glazing compound	4.32291	0.11710849	0.12043374

Table A2. Film distress deduct values for painted wood substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Swelling/Delamination Deduct Value
A+	0	0	0
A	4.8	8.4	10.3
A-	22.6	31	40.6
B+	41.8	52.4	67.3
B	55.4	66.2	82.1
B-	67.3	77.6	92.1
C+	74.6	84.2	97.3
C	81	89.9	100
C-	90	96.67	100

Table A3. Film distress deduct values for galvanized steel substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.7	16.1	16.8
A-	16.3	40.5	39.75
B+	30.9	61.1	60.75
B	43.5	76.2	70.7
B-	56.8	90.9	93.33
C+	66.1	100	100
C	74.4	100	100
C-	100	100	100

Table A4. Film distress deduct values for concrete, brick, stucco and cmu substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.7	3.7	3.7
A-	16.3	16.3	16.3
B+	30.9	30.9	30.9
B	43.5	43.5	43.5
B-	56.8	56.8	56.8
C+	66.1	66.1	66.1
C	74.7	74.7	74.7
C-	90	90	90

Table A5. Film distress deduct values for aluminum substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.7	3.7	6.89
A-	16.3	16.3	30.9
B+	30.9	30.9	56.7
B	43.5	43.5	75.4
B-	56.8	56.8	92.2
C+	66.1	66.1	100
C	74.7	74.7	100
C-	90	90	100

Table A6. Film distress deduct values for for polymeric substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.7	3.7	17.7
A-	16.3	16.3	41.1
B+	30.9	30.9	58.8
B	43.5	43.5	70.3
B-	56.8	56.8	80.5
C+	66.1	66.1	86.8
C	74.7	74.7	92.2
C-	90	90	100

Table A7. Film distress deduct values for for steel and iron substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	2.2	2.3	6.2
A-	16.5	18.1	32.4
B+	37.7	41.2	60.8
B	56.3	60.4	79.4
B-	75.6	79	94
C+	88.8	91.1	100
C	100	100	100
C-	100	100	100

Table A8. Film distress deduct values for for glazing compound.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.7	3.7	8.58
A-	16.3	16.3	34.2
B+	30.9	30.9	59.6
B	43.5	43.5	77
B-	56.8	56.8	92.2
C+	66.1	66.1	100
C	74.7	74.7	100
C-	90	90	100

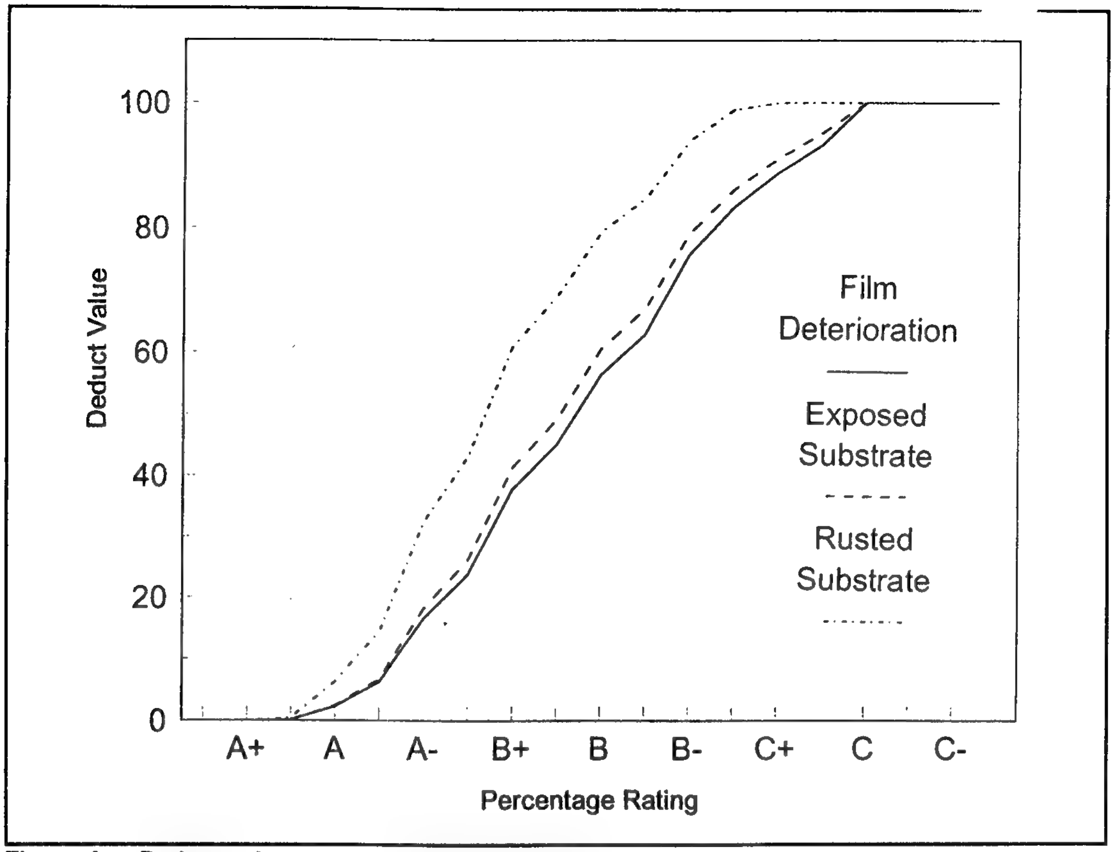


Figure A1. Deduct value curves for steel substrates.

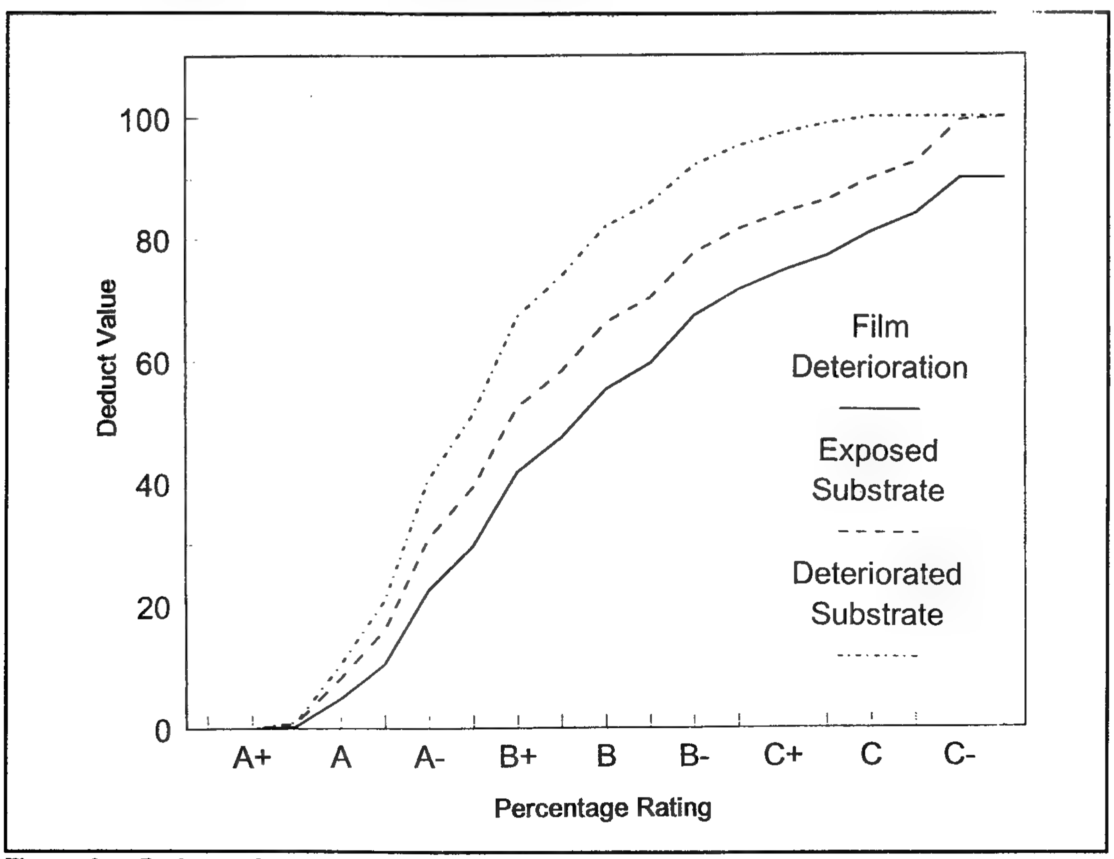


Figure A2. Deduct value curves for wood substrates.

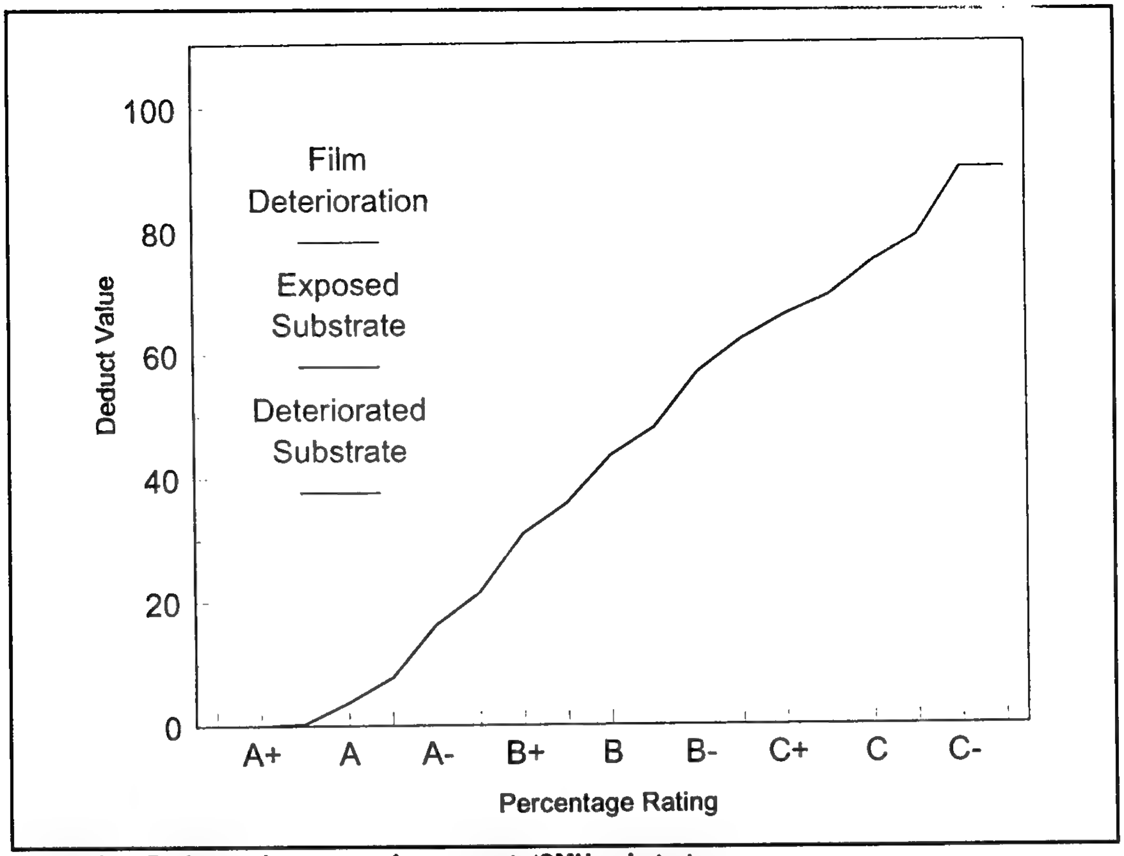


Figure A3. Deduct value curves for concrete/CMU substrates.

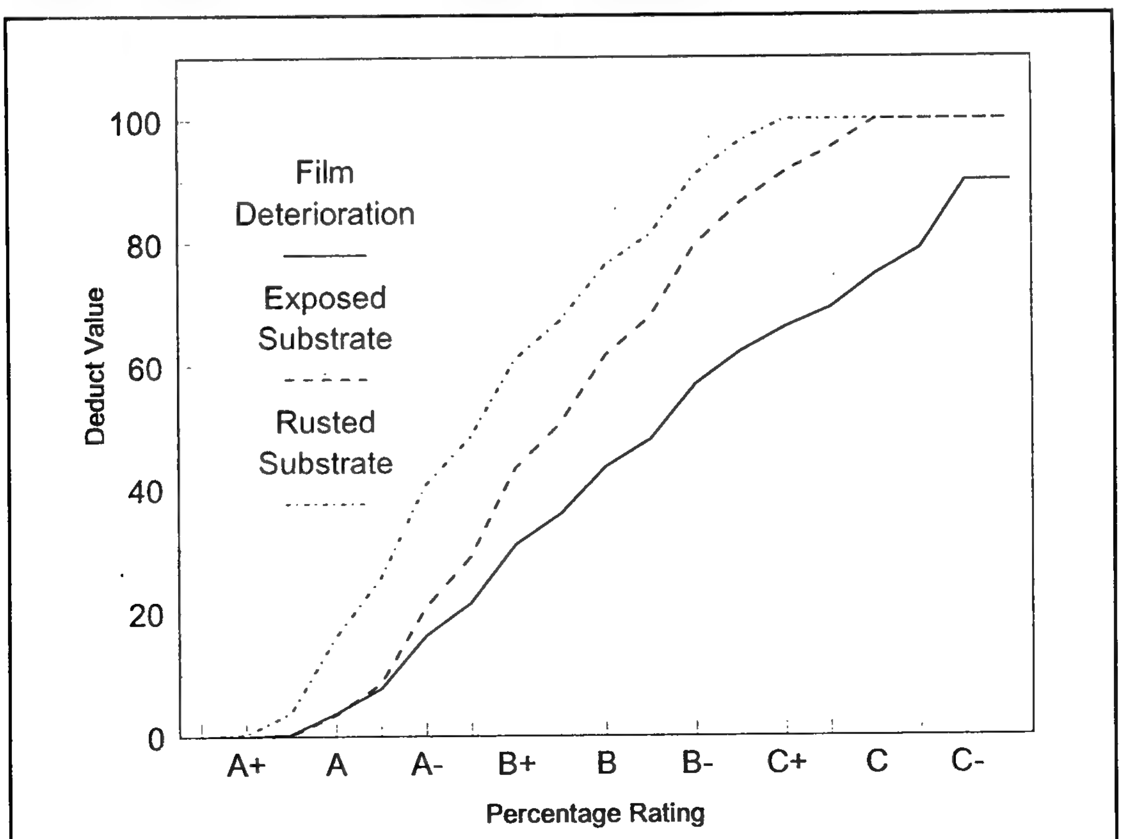


Figure A4. Deduct value curves for galvanized steel substrates.

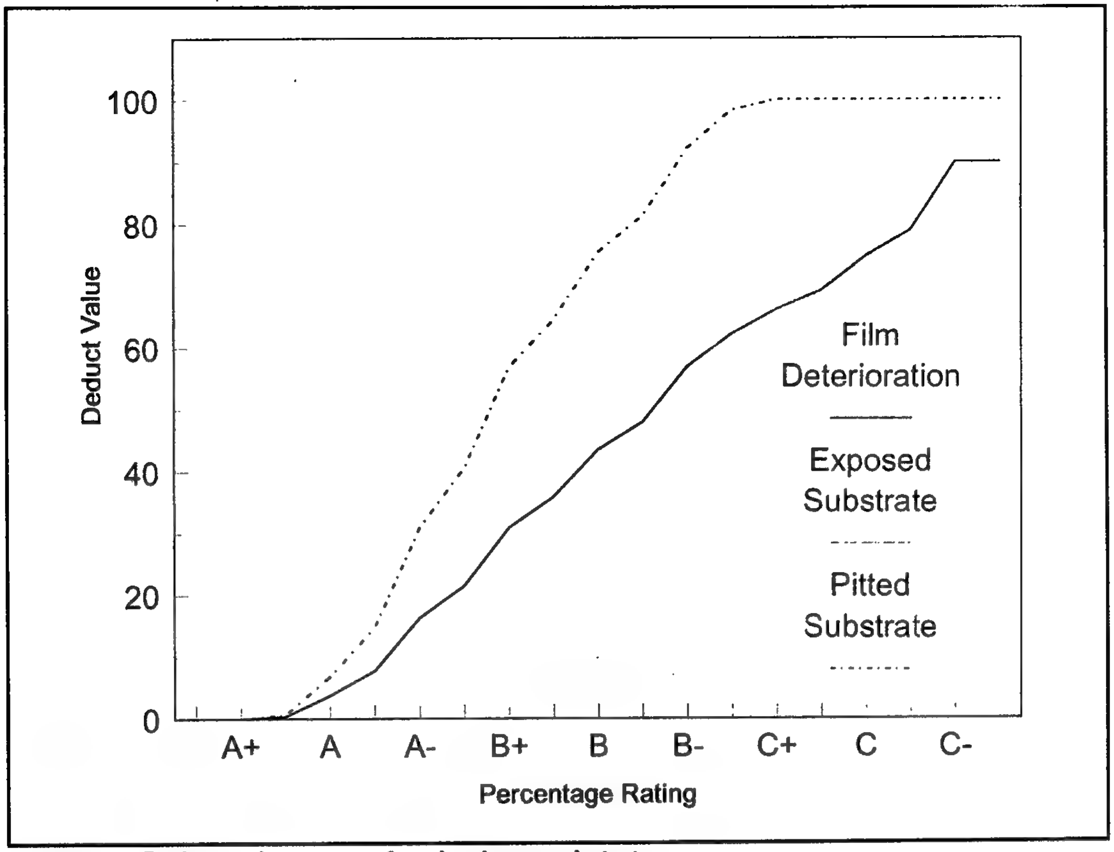


Figure A5. Deduct value curves for aluminum substrates.

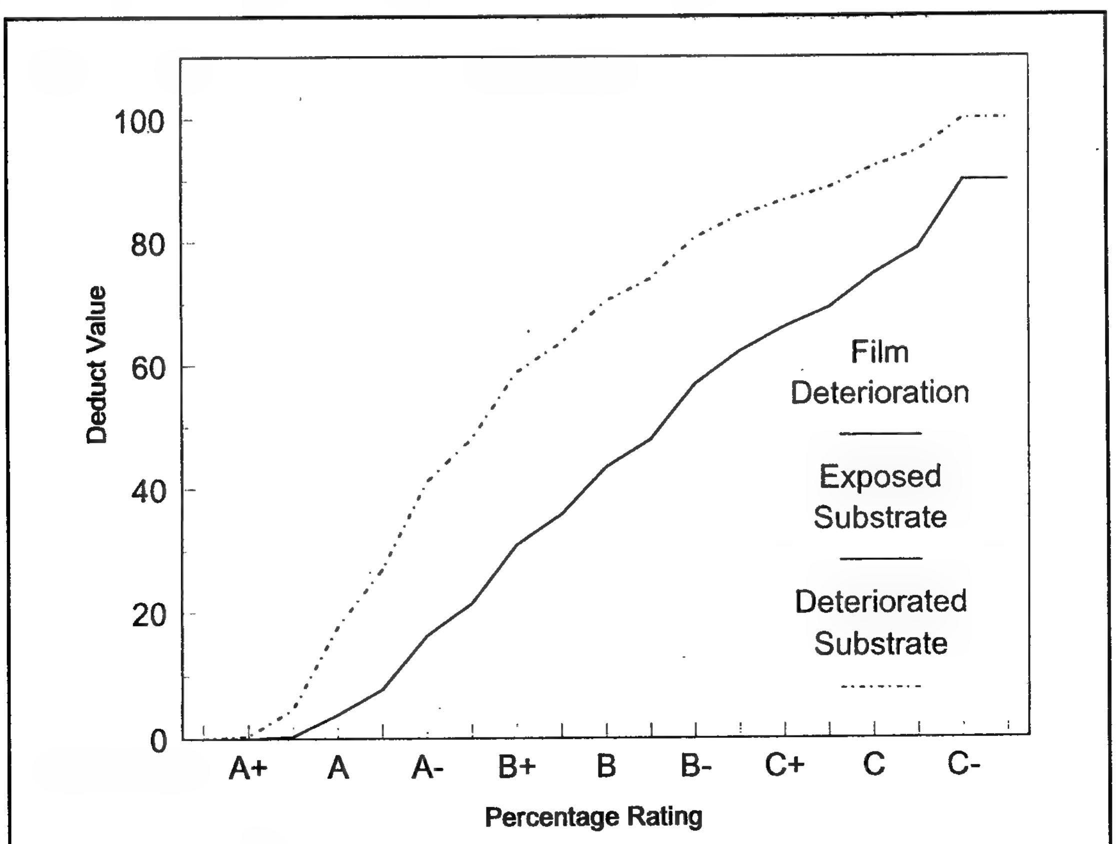


Figure A6. Deduct value curves for plastic substrates.

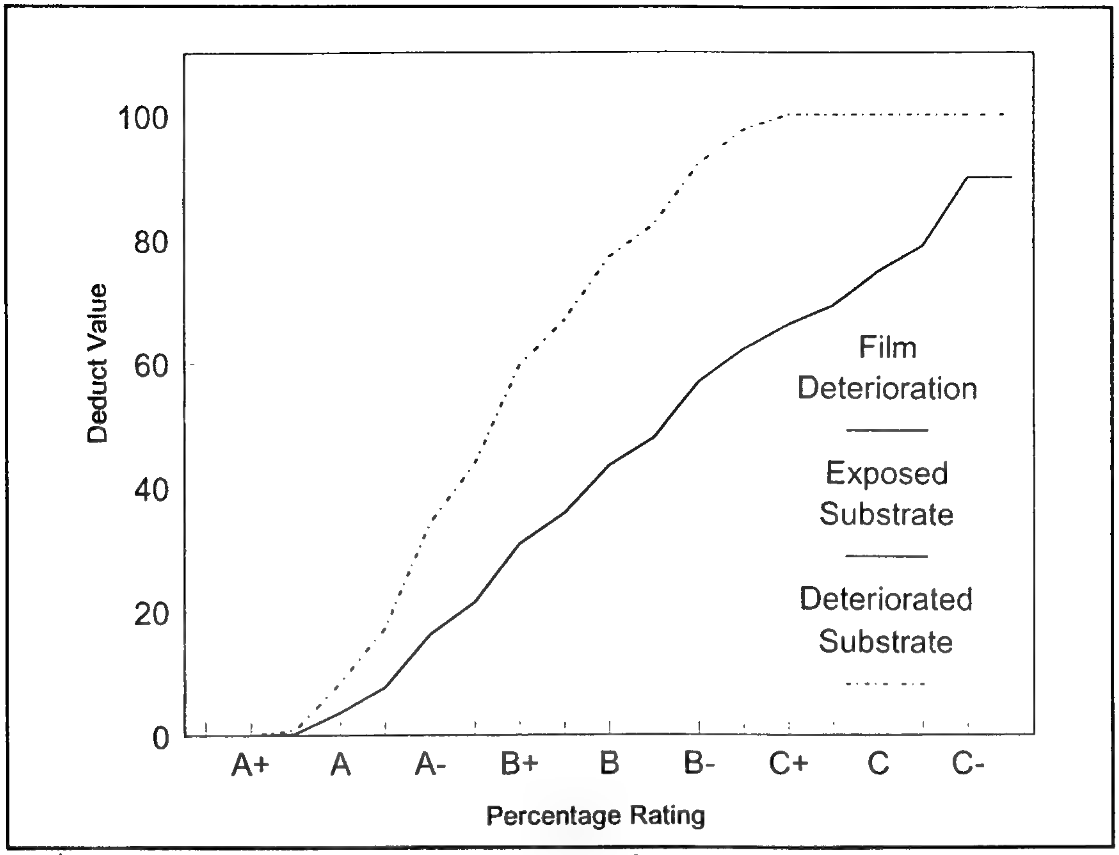


Figure A7. Deduct value curves for glazing compound.

Appendix B: PAINTER Appearance Distress Deduct Value Constants, Graphs and Table

Equation: $DV = a + bx + c\sqrt{x}\ln x + d\sqrt{x} + e\ln x$

Where a, b, c, d, and e are as follows in the Table below.

Table B1. Appearance distress deduct value constants.

	Localized High Contrast Distresses	Widespread High Contrast Distresses	Localized Low Contrast Distresses	Widespread Low Contrast Distresses
a	7.3889974	14.575139	0.13404212	7.1851943
b	1.5725354	1.1944803	0.6530749	0.32461765
c	-10.10616	-8.448831	-4.8226339	-3.4076167
d	39.80784	34.959843	23.2152	18.901694
e	0.59641457	1.2165886	-0.049586535	0.56440963

Table B2. Appearance codes.

Appearance Code	Localized High Contrast Deduct Value	Widespread High Contrast Deduct Value	Localized Low Contrast Deduct Value	Widespread Low Contrast Deduct Value
U*				
A+	15	18.1	5.7	8.9
A	23.1	26.1	9.6	12.9
A-	31.8	34.6	14.2	17.2
B+	43.8	45.9	21	23.6
B	57.3	59	29.5	31.6
B-	72	73.4	40.5	42.3
C+	79.8	81.5	48	49.9
C	85	87.2	54.8	56.8
C-	93.2	95	67.6	68.6

* An appearance Code of U has a Deduct value of 1.0

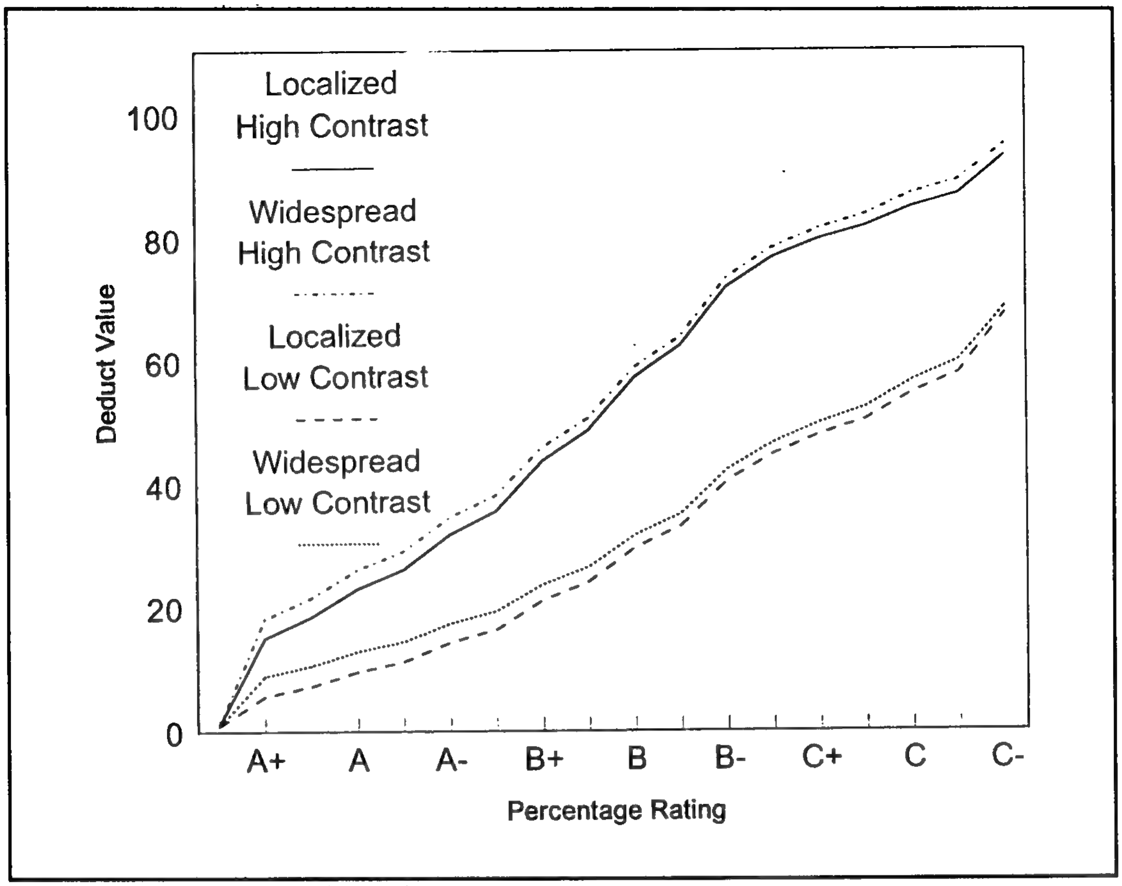


Figure B1. Appearance deduct value curve.

Appendix C: PAINTER Inventory Worksheet

PAINTER Inventory Worksheet

Building No.:	Date:	Page of
Face:	Installation:	Inspector:

Item No.	Item Description Code	Substrate Code	Area (sq. ft.)	Lead Paint Code	Calculations / Remarks

SKETCHES / NOTES:

Appendix D: PAINTER Inspection Form

PAINTER Inspection Form

Building No.: 2235 | Date: | Page 1 of 1

Face: B | Installation: Fort Example | Inspector:

Appearance: Uniformity: Yes ☐ No ☐

If Non-Uniform: Mildew, Chalky or Dirty Only: Yes ☐ No ☐

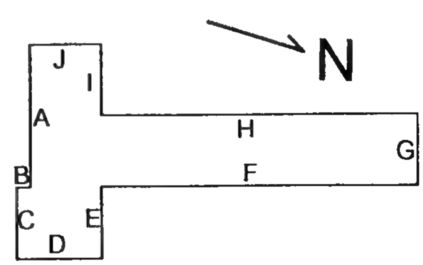
High Contrast: Localized ☐ Wide-Spread ☐ Percentage Code ___

Low Contrast: Localized ☐ Wide-Spread ☐ Percentage Code ___

Item No.	Component			Film Det Code	Substrate			Extent			Remarks
	Desc Code	Subs Code	Qty		Exp Code	Det Code	Qty Rpl	Localized	Wide-Spread	None	
1	WAL	CMU	3952								
2	DOR	WOD	64								
3	WND	STL	997								
4	DFR	STL	14								
5	FAC	CCT	2283								
6	STP	CCT	378								
7	VNT	STL	6								
8											
9											
10											
11											
12											

GRADING CODES	
A+	0% - .03%
A	.03% - .1%
A-	.1% - .3%
B+	.3% - 1%
B	1% - 3%
B-	3% - 10%
C+	10% - 17%
C	17% - 33%
C-	33% - 100%

NOTES:



Appendix E: PAINTER Economic Analysis Tables

Table E1. M&R Actions for high contrast non-uniform paint distresses.

Extent of Distress	Distress Condition	M&R Action
Localized	Deteriorated and exposed substrate	Treat, repair or replace deteriorated substrate, Perform surface preparation necessary, Prime new and unpainted substrate, Apply a finish coat to the affected area.
Localized	Exposed substrate	Perform surface preparation necessary, Prime unpainted substrate, Apply a finish coat to the affected area.
Localized	Exposed Undercoat	Perform surface preparation and apply a finish coat to the affected area.
Widespread	Deteriorated and exposed substrate	Treat, repair or replace deteriorated substrate, Perform surface preparation necessary, Prime new and unpainted substrate, Apply a finish coat to the entire surface area.
Widespread	Exposed substrate	Perform surface preparation necessary, Prime unpainted substrate, Apply a finish coat to the entire surface area.
Widespread	Exposed undercoat	Perform surface preparation and Apply a finish coat to the entire surface area.

Table E2. CCI vs. surface preparation options.

Coating Condition Index	Surface Preparation Options
71-100	Do Nothing
56-70	Hand Tools
41-55	Power Equipment
0-40	Power Tools or Other Mechanical Methods

Table E3. Substrate vs surface preparation options.

Substrate	Hand Tools	Power Tools	Power Wash	Steam Clean	Water Blast	Brush-off Blast	Commercial Blast	Near-white Metal Blast
Wood Plywood Manuf'ed wood Stucco Brick	X	X	X	X				
Aluminum Concrete CMU	X	X	X	X	X	X		
Polymers Glass	X	X	X	X	X			
Galvanized Steel	X	X	X	X	X	X		
Steel	X	X	X	X	X	X	X	X
Glazing compound	X							

Table E4. Typical surface preparation costs per square foot.

Surface Preparation Method	Work from the Ground	Work From Ladders	Work From Scaffolding/ Man-lifts
Glazing	$1.2065	$1.9304	$1.4194
Cleaning/washing			
Wash	$0.0856	$0.1369	$0.1007
Hand tools	$0.4438	$0.7101	$0.5221
Power tools	$0.2496	$0.3994	$0.2937
Power wash	$0.0571	$0.0913	$0.0671
Steam clean	$0.0799	$0.1278	$0.0940
Water blast	$0.0499	$0.0799	$0.0587
Abrasive blasts			
Concrete and masonry	$0.2038	$0.3261	$0.2398
SSPC 7 brush-off	$0.0873	$0.1398	$0.1028
SSPC 6 commercial	$0.2223	$0.3557	$0.2616
SSPC 10 near-white metal	$0.5095	$0.8152	$0.5994

Table E5. Typical brush painting costs per square foot.

Material	One Coat From the Ground	One Coat From Ladders	One Coat From Scaffolding/ Man-lifts	2 coat Mult. Factor	3 coat Mult. Factor
Wood/wood products	$0.3445	$0.5383	$0.4053	1.60	2.40
Steel	N/A	N/A	N/A	N/A	N/A
Aluminum	$0.2067	$0.3230	$0.2432	1.67	2.17
Galvanized metal	N/A	N/A	N/A	N/A	N/A
CMU (block filler/sSealer)	$0.5168	$0.8075	$0.6080	N/A	N/A
CMU (paint)	$0.2756	$0.4307	$0.3243	1.63	N/A
Stucco	$0.1378	$0.2153	$0.1621	2.00	N/A
Concrete	N/A	N/A	N/A	N/A	N/A
Brick	N/A	N/A	N/A	N/A	N/A
Trim	$0.3445	$0.5383	$0.4053	1.60	2.00
Pipe/conduit	$0.4615	$0.7211	$0.5430	1.54	2.31
Machinery/ equipment	$0.7100	$1.1094	$0.8353	1.35	2.00

Table E6. Typical roller painting costs per square foot.

Material	One Coat From the Ground	One Coat From Ladders	One Coat From Scaffolding/ Man-lifts	2 Coat Mult. Factor	3 Coat Mult. Factor
Wood/wood products	$0.2412	$0.3768	$0.2837	1.57	2.14
Steel	N/A	N/A	N/A	N/A	N/A
Aluminum	$0.1723	$0.2692	$0.2027	1.60	2.20
Galvanized metal	N/A	N/A	N/A	N/A	N/A
CMU (block filler/sealer)	$0.2412	$0.3768	$0.2837	N/A	N/A
CMU (paint)	$0.1378	$0.2153	$0.1621	1.75	N/A
Stucco	$0.1378	$0.2153	$0.1621	2.00	N/A
Concrete	$0.1378	$0.2153	$0.1621	1.75	N/A
Brick	$0.2756	$0.4307	$0.3243	1.63	N/A
Trim	N/A	N/A	N/A	N/A	N/A
Pipe/conduit	N/A	N/A	N/A	N/A	N/A
Machinery/equipment	$0.4615	$0.7211	$0.5430	1.23	1.85

Table E7. Typical spray gun painting costs per square foot.

Material	One Coat From the Ground	One Coat From Ladders	One Coat from Scaffolding/ Man-lifts	2 Coat Mult. Factor	3 Coat Mult. Factor
Wood/wood products	$0.1067	$0.1667	$0.1255	2.0	2.67
Steel	$0.1067	$0.1667	$0.1255	1.33	2.33
Aluminum	$0.1067	$0.1667	$0.1255	1.33	2.33
Galvanized metal	$0.1067	$0.1667	$0.1255	1.33	2.33
CMU (block filler/sealer)	$0.1422	$0.2223	$0.1673	N/A	N/A
CMU (paint)	$0.1067	$0.1667	$0.1255	1.67	2.00
Stucco	$0.1067	$0.1667	$0.1255	1.33	N/A
Concrete	$0.1067	$0.1667	$0.1255	1.33	N/A
Brick	$0.1422	$0.2223	$0.1673	1.5	N/A
Trim	N/A	N/A	N/A	N/A	N/A
Pipe/conduit	$0.2134	$0.3334	$0.2510	1.67	2.50
Machinery/ equipment	$0.1778	$0.2778	$0.2092	1.80	2.60

Table E8. Typical costs of paint and coating materials.

Paint/Coating Material	Cost per Ft^2
Latex paint (TT-P-19)	$0.0440
Alkyd paint (TT-P-102)	$0.0680
Block filler (AA 1555)	$0.1020
Epoxy paint (MIL-P-24441)	$0.0892
Epoxy paint (TT-C-535)	$0.0763
Urethane paint (MIL-C-83286)	$0.0664
Urethane paint (MIL-C-85285)	$0.1207
Glazing compound (TT-P-00791)	$0.0851
Glazing compound (AA-373)	$0.0737
Blasting abrasive (concrete)	$0.1400
Blasting abrasive (masonry)	$0.1600
Blasting abrasive (SSPC 7)	$0.1167
Blasting abrasive (SSPC 6)	$0.3033
Blasting abrasive (SSPC 10)	$0.4200

Table E9. Typical in-place costs for other building materials.

Miscellaneous Materials	Cost per Ft^2
Steel siding	$3.053
Aluminum siding	$3.167
Vinyl siding	$2.667

Table E10. Labor correction factors by state.

State	Common Building Laborers	Air Tool Operators	Glaziers	Ordinary Painters	Spray Painters	Structural Steel Painters
AL	0.663	0.641	0.801	0.799	0.846	0.843
AK	1.771	1.783	1.410	1.698	1.696	1.698
AZ	1.050	1.107	0.955	0.937	0.930	0.946
AR	0.668	0.712	0.619	0.689	0.703	0.679
CA	1.683	1.670	1.541	1.507	1.460	1.467
CO	0.855	0.837	1.018	0.918	0.931	0.985
CT	1.375	1.363	1.327	1.301	1.401	1.360
DE	1.289	1.279	1.570	1.257	1.248	1.250
DC	0.950	1.007	1.207	1.284	1.244	1.246
FL	0.702	0.721	0.737	0.773	0.782	0.779
GA	0.627	0.615	0.737	0.765	0.742	0.741
HI	1.534	1.591	1.666	1.836	1.806	1.809
ID	1.212	1.197	0.891	0.983	0.998	1.000
IL	1.238	1.204	1.123	1.186	1.171	1.173
IN	1.115	1.103	1.065	1.097	1.011	1.014
IA	0.823	0.818	0.905	0.849	0.847	.0846
KS	0.706	0.704	0.892	0.844	0.850	0.855
KY	1.033	1.026	0.953	0.991	1.000	0.958
LA	0.675	0.670	0.763	0.720	0.734	0.730
ME	0.897	0.895	0.651	0.584	0.561	0.562
MD	1.013	1.016	1.163	0.984	1.028	1.029
MA	1.469	1.504	1.444	1.506	1.506	1.582
MI	1.112	1.101	0.938	1.047	1.045	1.047
MN	1.131	1.122	1.112	1.188	1.180	1.182
MS	0.565	0.569	0.717	0.641	0.663	0.664
MO	1.073	1.058	1.168	1.021	1.018	1.011
MT	0.977	0.968	0.754	0.856	0.905	0.866

State	Common Building Laborers	Air Tool Operators	Glaziers	Ordinary Painters	Spray Painters	Structural Steel Painters
NE	0.853	0.847	0.935	0.783	0.792	0.786
NV	1.276	1.265	1.344	1.278	1.215	1.257
NH	0.969	1.030	1.002	0.739	0.738	0.739
NJ	1.296	1.196	1.530	1.503	1.364	1.341
NM	0.777	0.797	0.807	0.717	0.724	0.726
NY	1.357	1.316	1.225	1.277	1.315	1.326
NC	0.549	0.538	0.689	0.718	0.765	0.767
ND	0.658	0.670	0.532	0.697	0.716	0.717
OH	1.172	1.160	1.089	1.125	1.109	1.134
OK	0.635	0.690	0.846	0.829	0.849	0.845
OR	1.314	1.310	1.262	0.939	0.937	0.939
PA	1.135	1.124	1.161	1.133	1.151	1.151
RI	1.520	1.512	1.468	1.500	1.509	1.469
SC	0.585	0.606	0.637	0.718	0.752	0.753
SD	0.629	0.630	0.587	0.629	0.649	0.650
TN	0.692	0.677	0.817	0.851	0.862	0.842
TX	0.671	0.669	0.786	0.795	0.789	0.788
UT	0.890	0.888	0.844	0.792	0.782	0.772
VT	0.876	0.858	0.555	0.756	0.732	0.733
VA	0.636	0.643	0.782	0.731	0.724	0.724
WA	1.269	1.260	1.086	1.126	1.108	1.110
WV	1.183	1.175	0.910	1.063	1.066	1.074
WI	1.113	1.092	1.038	0.962	0.962	0.955
WY	0.767	0.767	0.943	1.077	1.077	1.078

Appendix F: PAINTER EMS Paint History Data

The Paint History records maintained by PAINTER EMS include the following for each building and structure included within the PAINTER database:

Coating Condition Index History and Records

- Coating Condition Index
- Appearance Condition Index
- Film Condition Index
- Inspection Date
- Inspector

Lead-Based Paint Data

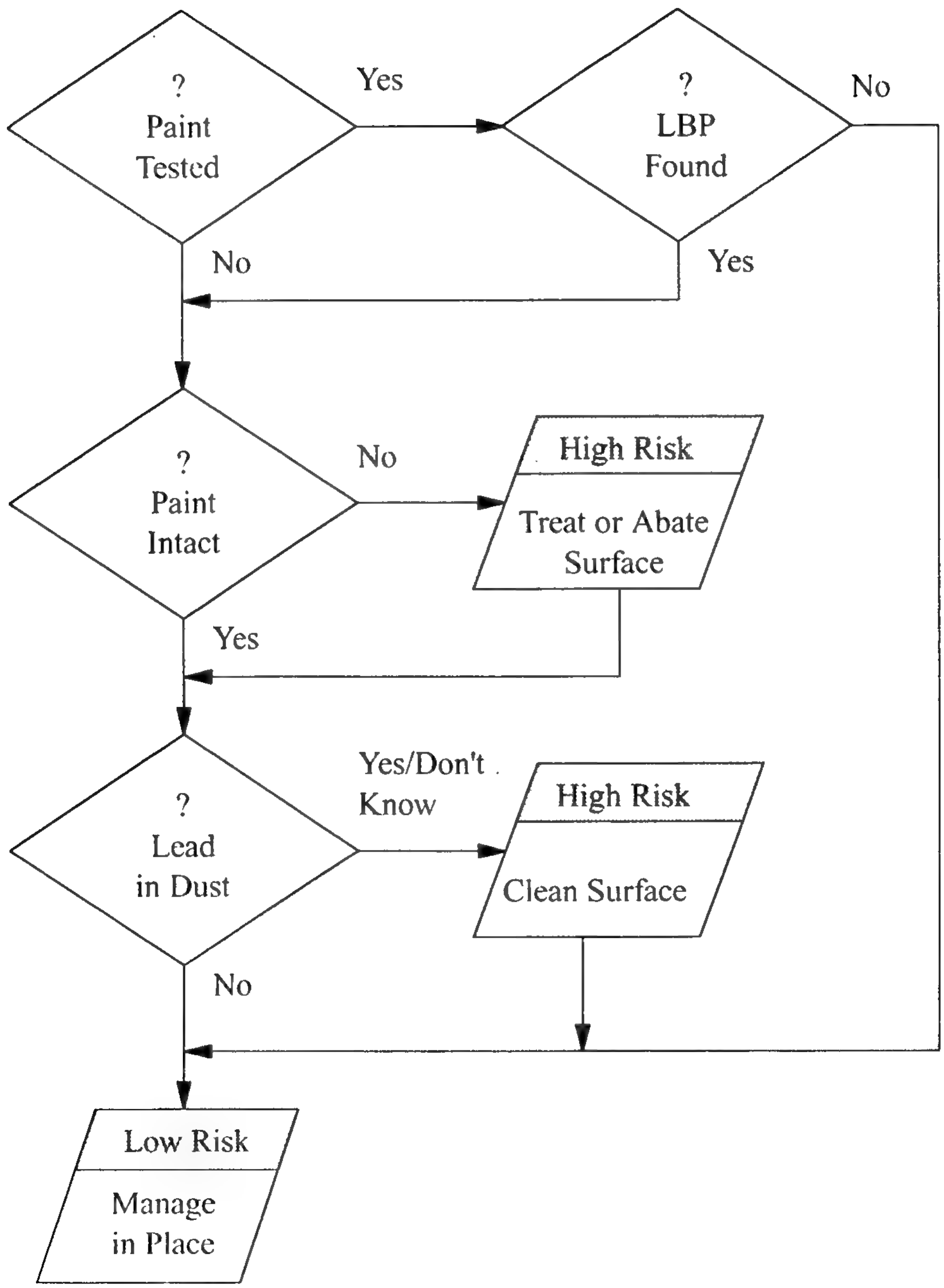
- Presence of lead-based paint
- Measured lead level

Paint History and Records

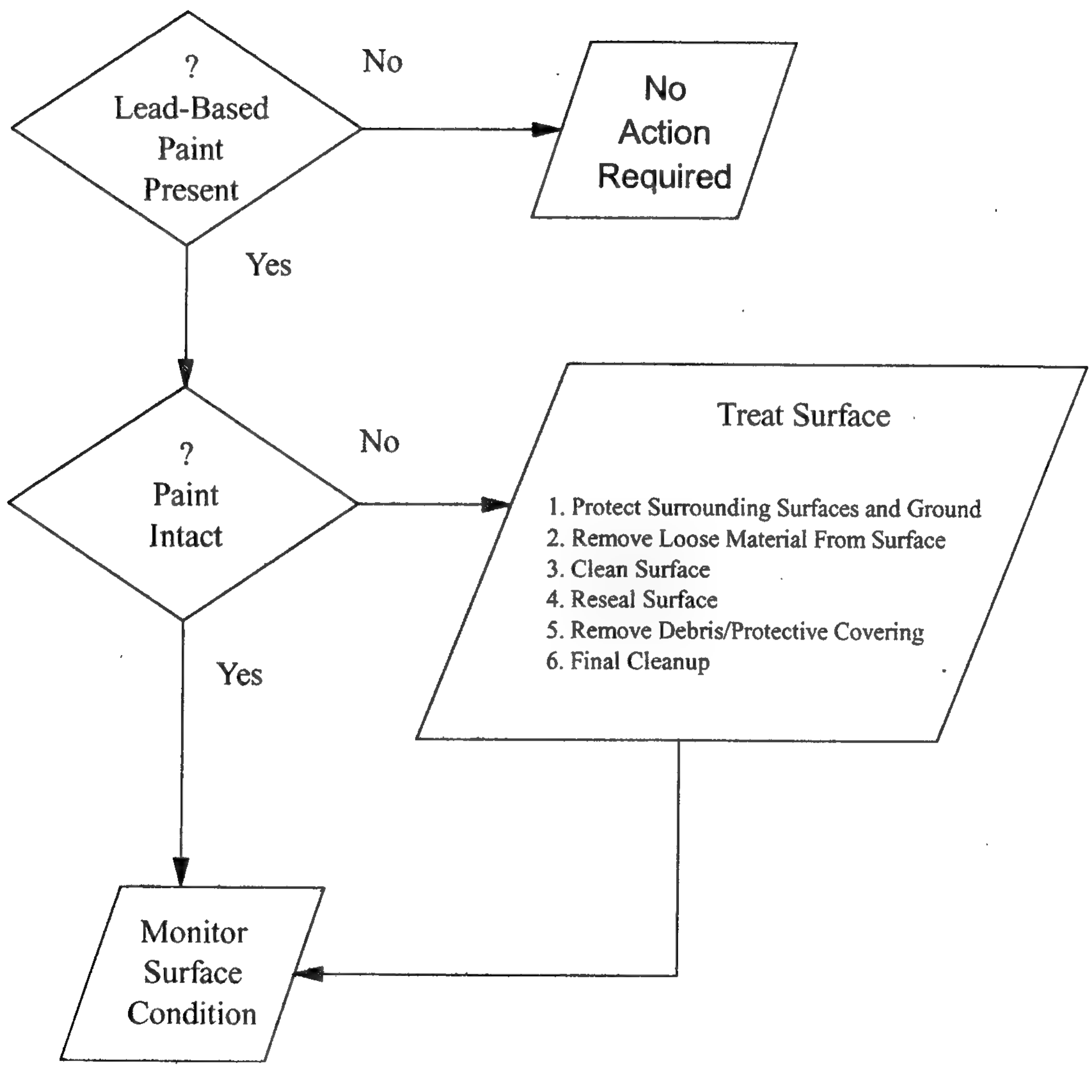
- Date painted
- Paint systems used
- Surface Preparation employed
- Contractor
- Project No./Contract No.
- Primer (if any):
    - Trade Name
    - Manufacturer
    - Spec. Number
    - Color ID
    - Thinner Used
    - Application Method
    - Dry Film Thickness
- Intermediate Coat (if any):
    - Trade Name
    - Manufacturer
    - Spec. Number
    - Color ID
    - Thinner Used
    - Application Method
    - Dry Film Thickness
- Top Coat:
    - Trade Name
    - Manufacturer
    - Spec. Number
    - Color ID
    - Thinner Used
    - Application Method
    - Dry Film Thickness

Appendix G: Flow Chart of Decision Process for Dealing with Lead-Based Paint

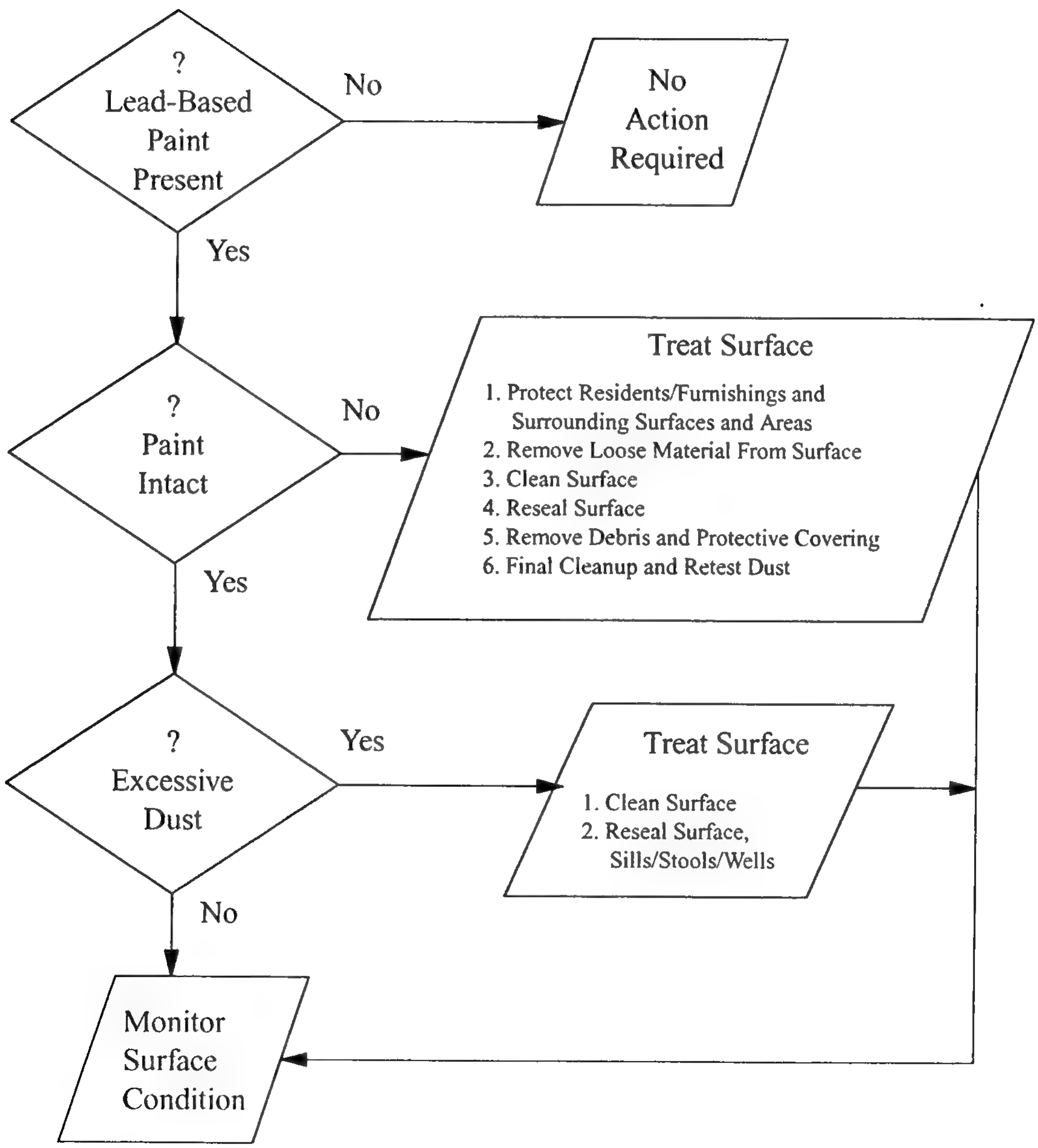
LEAD EXPOSURE RISK ASSESSMENT



IN-PLACE MANAGEMENT
OF
BUILDING EXTERIORS



IN-PLACE MANAGEMENT OF BUILDING INTERIORS



Appendix H: PAINTER Film and Appearance Distress Deduct Graphs for Lead-Based Paint

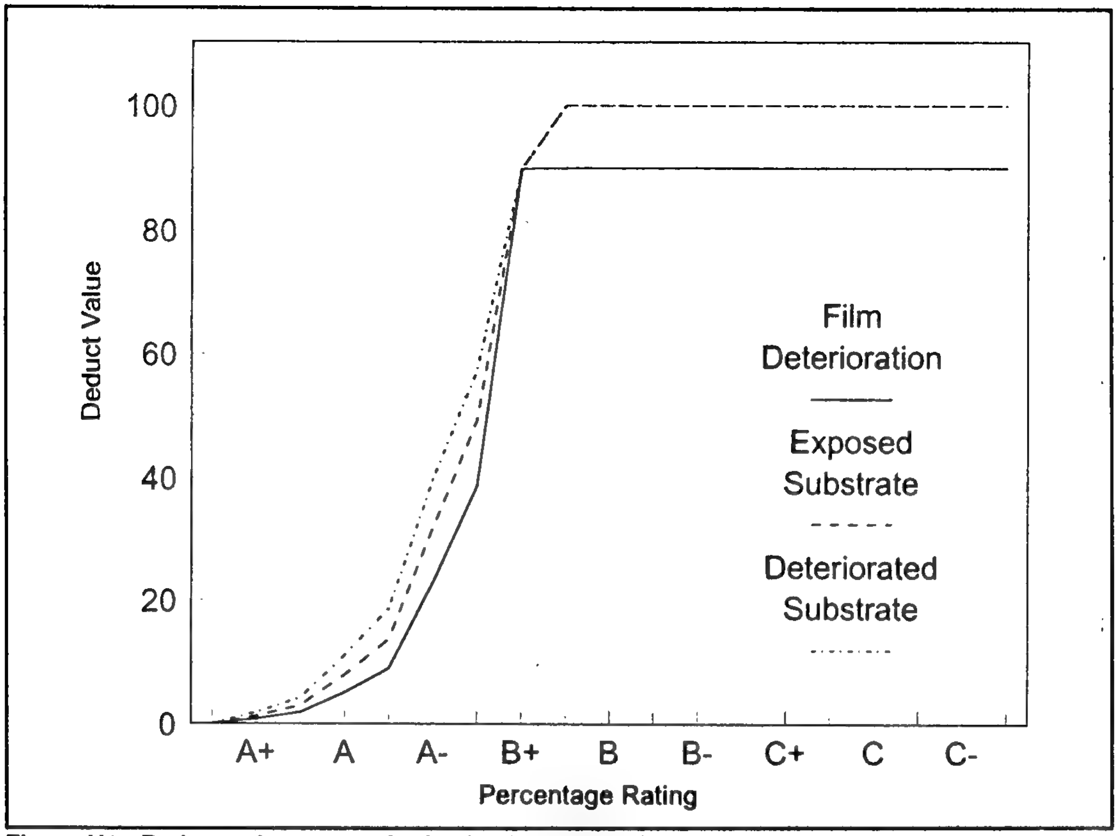


Figure H1. Deduct value curves for lead paint on wood.

Table H1. Deduct value for painted wood substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Swelling/ Delamination Deduct Value
A+	0	0	0
A	5.1	8	11.1
A-	22.8	31.8	39.7
B+	89.9	89.9	89.9
B	90	100	100
B-	90	100	100
C+	90	100	100
C	90	100	100
C-	90	100	100

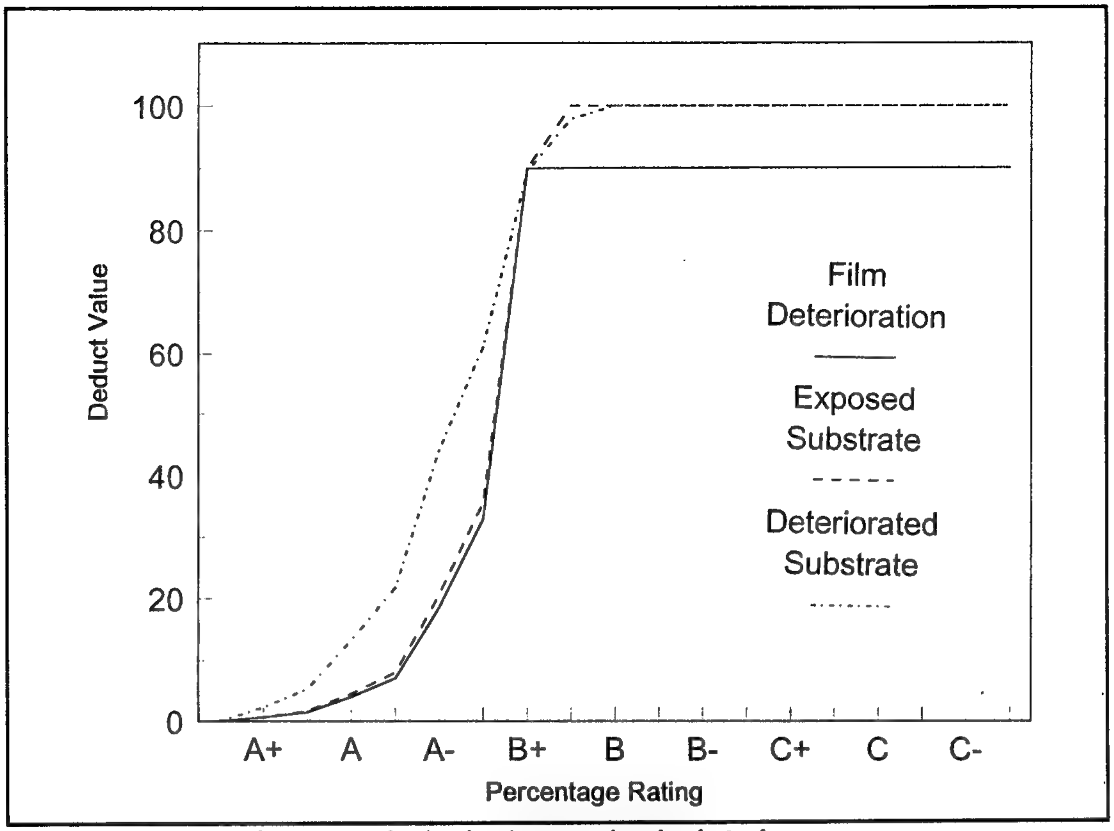


Figure H2. Deduct value curves for lead paint on galvanized steel.

Table H2. Deduct value for galvanized steel substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.5	4.5	13.2
A-	16.7	20.5	44.1
B+	90	90	89.4
B	90	100	100
B-	90	100	100
C+	90	100	100
C	90	100	100
C-	90	100	100

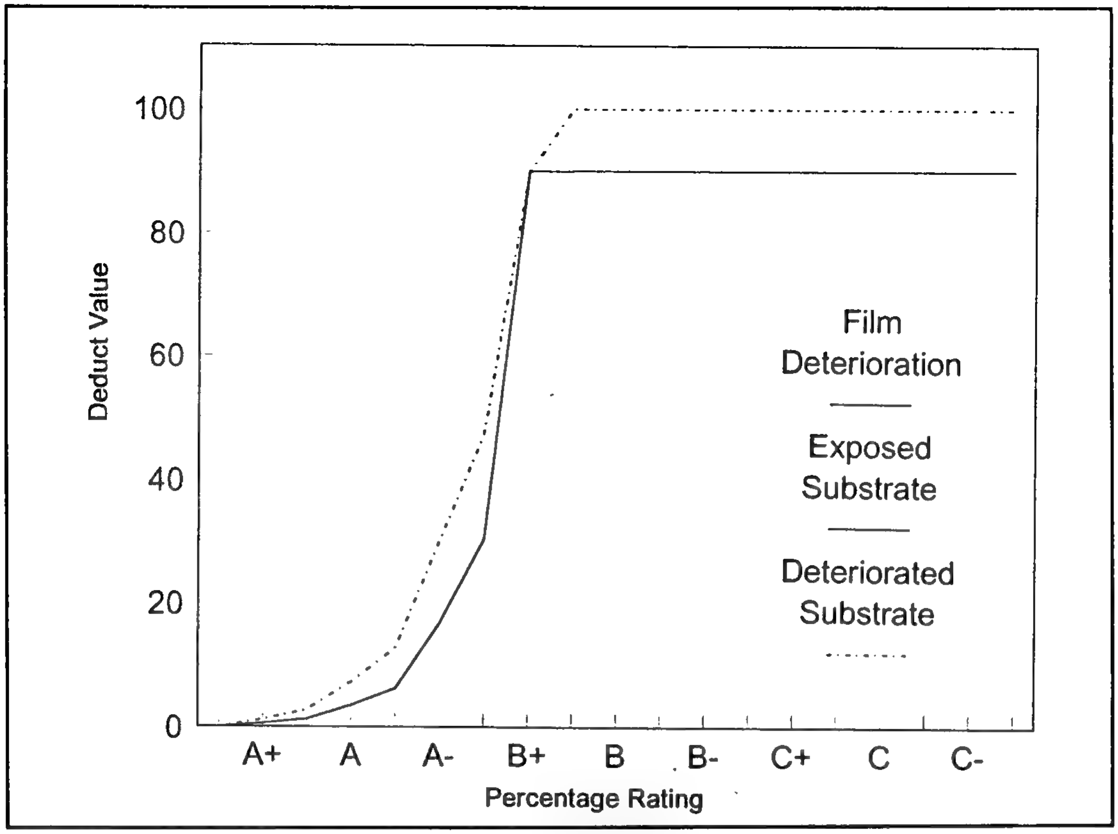


Figure H3. Deduct value curves for lead paint on aluminum.

Table H3. Deduct value for aluminum substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.5	3.5	7.4
A-	16.7	16.7	30
B+	90	90	89.9
B	90	90	100
B-	90	90	100
C+	90	90	100
C	90	90	100
C-	90	90	100

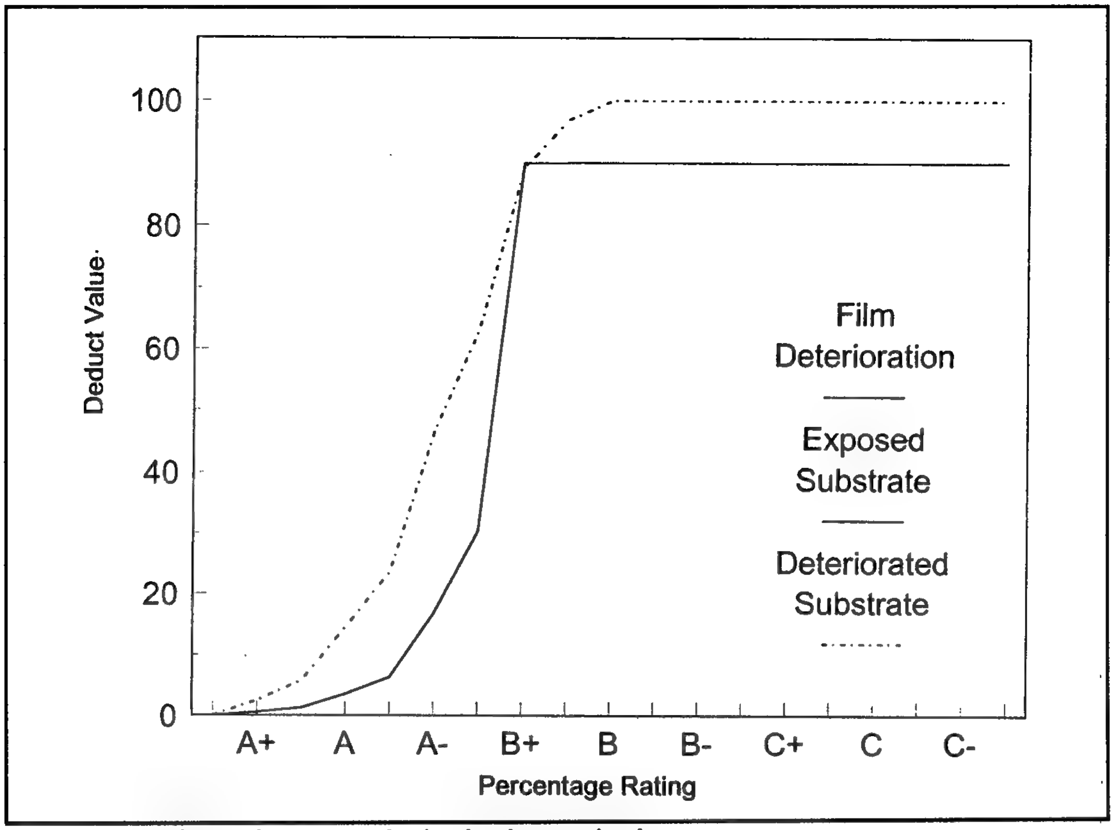


Figure H4. Deduct value curves for lead paint on plastics.

Table H4. Deduct value for painted wood substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.5	3.5	14.4
A-	16.7	16.7	46.4
B+	90	90	89.2
B	90	90	100
B-	90	90	100
C+	90	90	100
C	90	90	100
C-	90	90	100

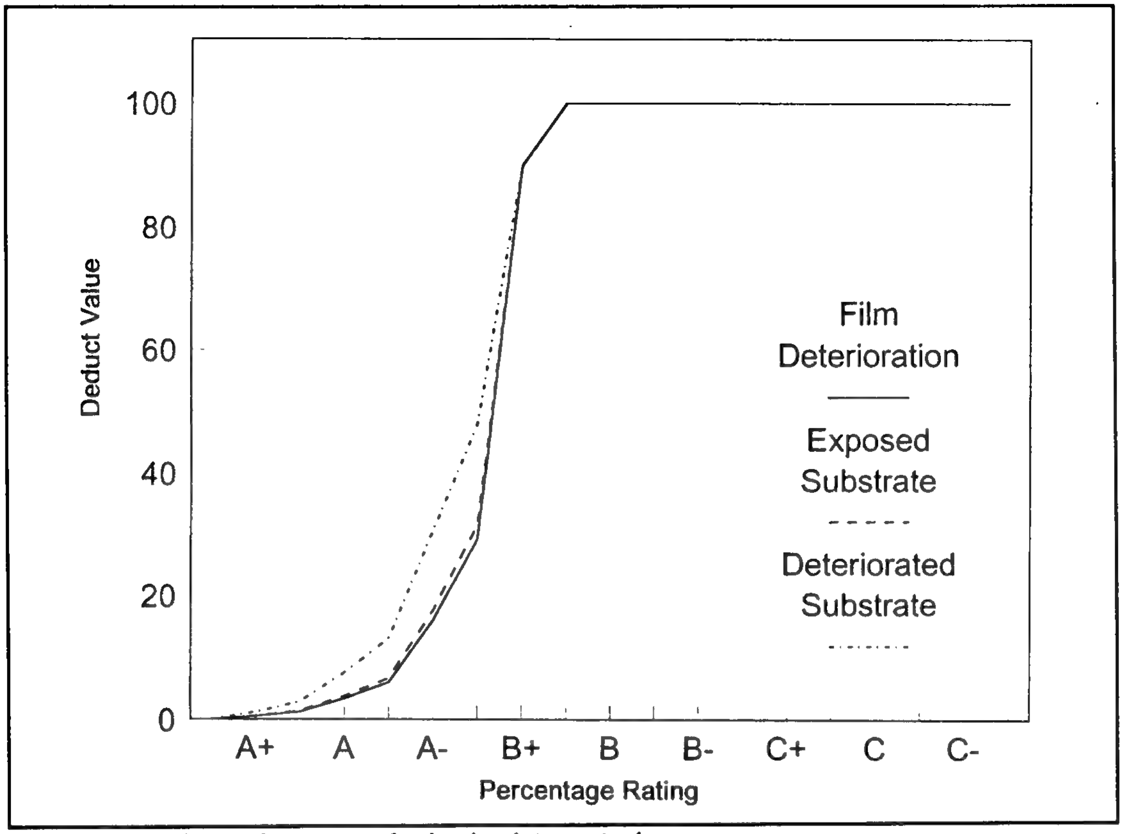


Figure H5. Deduct value curves for lead paint on steel.

Table H5. Deduct value for steel and iron substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.3	3.7	7.6
A-	15.9	17.6	30.6
B+	90	90	89.9
B	100	100	100
B-	100	100	100
C+	100	100	100
C	100	100	100
C-	100	100	100

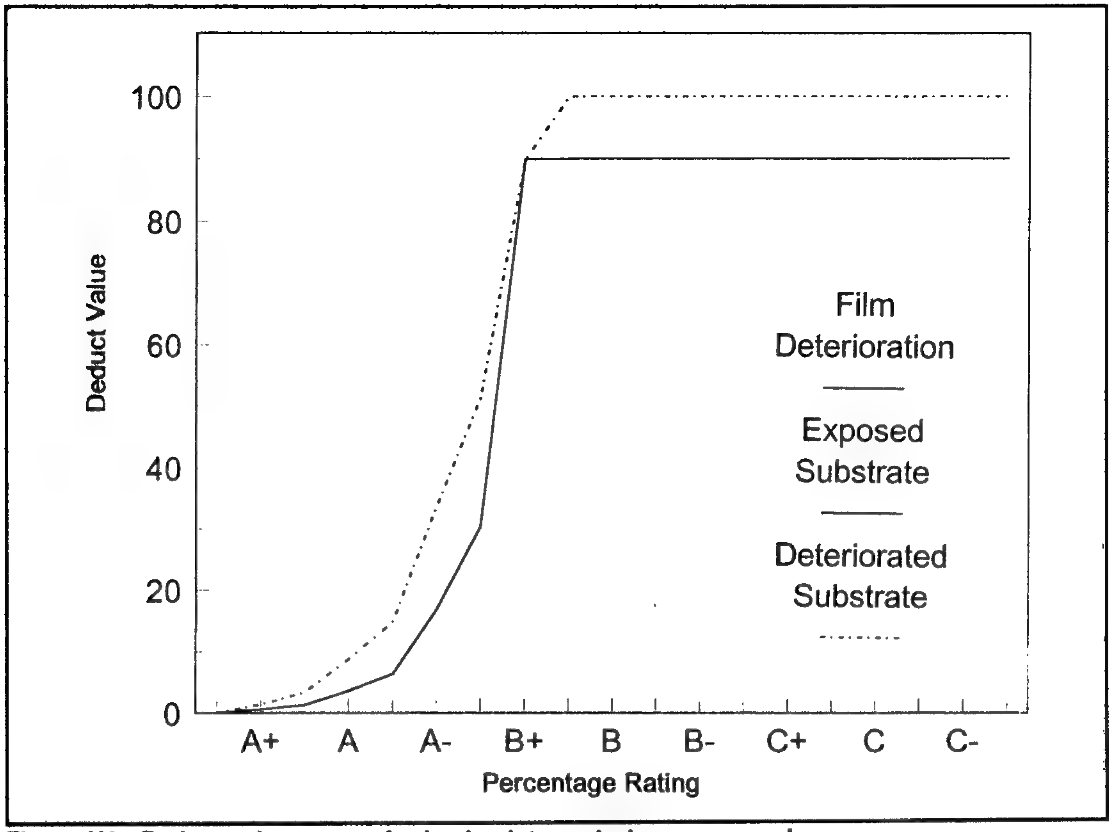


Figure H6. Deduct value curves for lead paint on glazing compound.

Table H6. Deduct value for glazing compound.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.5	3.5	8.6
A-	16.7	16.7	33.6
B+	90	90	89.9
B	90	90	100
B-	90	90	100
C+	90	90	100
C	90	90	100
C-	90	90	100

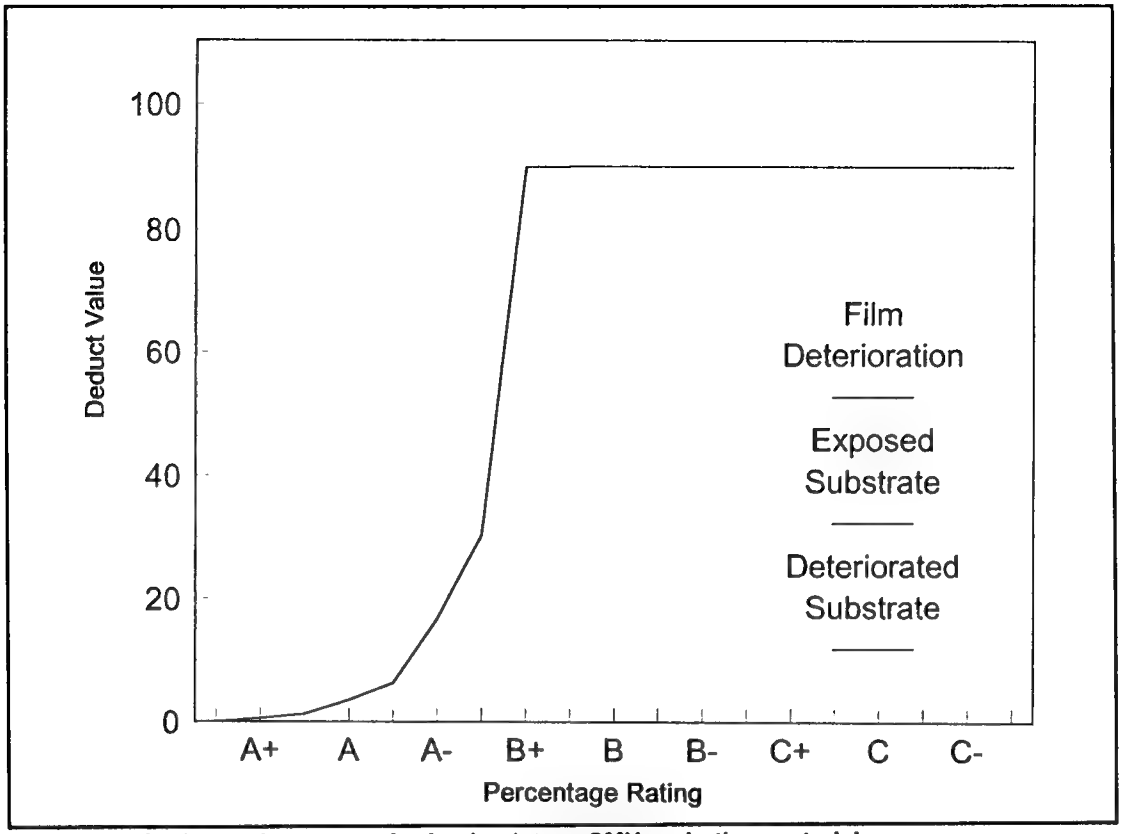


Figure H7. Deduct value curves for lead paint on CMU and other materials.

Table H7. Deduct value for concrete, brick, stucco and CMU substrates.

Survey Rating Code	Film Deterioration Deduct Value	Exposed Substrate Deduct Value	Deteriorated Substrate Deduct Value
A+	0	0	0
A	3.5	3.5	3.5
A-	16.7	16.7	16.7
B+	90	90	90
B	90	90	90
B-	90	90	90
C+	90	90	90
C	90	90	90
C-	90	90	90

Table H8. Distress levels for various substrates.

Substrate and Distress Level*	a	b	c
Film Deterioration on Steel	0.00746829	0.00357866	-0.00700973
Exposed Steel	0.007854184	0.003104818	-0.00622785
Rusted Steel	0.009490129	0.001098586	-0.0029239
Film Deterioration on Wood	0.008924101	0.002690305	-0.00445208
Exposed Wood	0.009572308	0.000998837	-0.00276226
Rotted/Swelling Wood	0.009992911	0.00048145	-0.00190617
Concrete / CMU / Others	0.007848182	0.004009412	-0.0066233
Exposed Galvanizing	0.008403383	0.0024304	-0.00511486
Rusted Galvanized Steel	0.010216577	0.000231589	-0.00155703
Pitted Aluminum	0.009455856	0.001143743	-0.00300624
Deteriorated Plastics	0.010320865	0.000116785	-0.00140137
Missing Glazing Compound	0.009692624	0.000853256	-0.00252753

*Equation: $1/y = a + b\, x \ln x - c \ln x/x$
Where the venue for a, b, and c are as stated in the appropriate columns.

Appendix I: Draft PAINTER EMS Training Outline

1 INTRODUCTION
- PAINTER EMS Background
- Training Scope and Overview

2 ENGINEER MANAGEMENT SYSTEM CONCEPTS AND COMPONENTS
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- EMS Components
- EMS Benefits

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- PAINTER Components

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  - Inventory Data Collection
- Project Level Inventory
  - Building Division
  - Inventory Data Collection
- Automated Inventory Collection

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- CCI Calculation

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- Micro PAINTER Structure
- Micro PAINTER Functions
- Inventory Data Entry Procedures
- Inspection Data Entry Procedures

7 PAINTER NETWORK LEVEL MANAGEMENT
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- Network Reports from Micro PAINTER
- Development of Network Level Work Plan
- Development of BMAR Retirement Plan

8 PAINTER PROJECT LEVEL MANAGEMENT
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Paint Deterioration Prediction and Cost Analysis
Determination of Paint Deterioration Predictions
General Database Report Generation
M&R Alternatives Analysis

9 PAINTER IMPLEMENTATION
Overview
General Procedures
PAINTER Implementation Steps

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CECG
ATTN: CECC-P
ATTN: CECW
ATTN: CECW-O
ATTN: CECW-P
ATTN: CECW-PR
ATTN: CEMP
ATTN: CEMP-E
ATTN: CEMP-C
ATTN: CEMP-M
ATTN: CEMP-R
ATTN: CERD-C
ATTN: CERD-ZA
ATTN: CERD-L
ATTN: CERD-M
ATTN: CERM
ATTN: DAEN-ZC
ATTN: DAIM-FDP

CECPW 22310-3862
ATTN: CECPW-E
ATTN: CECPW-FT
ATTN: CECPW-ZC
ATTN: DET III 79906

US Army Engr District
ATTN: Library (40)

US Army Engr Division
ATTN: Library (12)

US Army Europe
ATTN: AEAEN-EH 09014
ATTN: AEAEN-ODCS 09014
29th Area Support Group
ATTN: AERAS-FA 09054
100th Support Group
ATTN: AETT-EN-DPW 09114
222d Base Battalion
ATTN: AETV-BHR-E 09034
235th Base Support Battalion
ATTN: Unit 28614 Ansbach 09177
293d Base Support Battalion
ATTN: AEUSG-MA-AST-WO-E 09086
409th Support Battalion (Base)
ATTN: AETTG-DPW 09114
412th Base Support Battalion 09630
ATTN: Unit 31401
Frankfurt Base Support Battalion
ATTN: Unit 25727 09242
CMTC Hohenfels 09173
ATTN: AETTH-DPW
Mainz Germany 09185
ATTN: BSB-MZ-E
21st Support Command
ATTN: DPW (10)
US Army Berlin
ATTN: AEBA-EH 09235
ATTN: AEBA-EN 09235
SETAF
ATTN: AESE-EN-D 09613
ATTN: AESE-EN 09630
Supreme Allied Command
ATTN: ACSGEB 09703
ATTN: SHIHB/ENGR 09705

INSCOM
ATTN: IALOG-I 22060
ATTN: IAV-DPW 22186

USA TACOM 48397-5000
ATTN: AMSTA-XE

Defense Distribution Region East
ATTN: DDRE-WI 17070

HQ XVIII Airborne Corps 28307
ATTN: AFZA-DPW-EE

4th Infantry Div (MECH) 80913-5000
ATTN: AFZC-FE

US Army Materiel Command (AMC)
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